Compilation of 1991 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program

AD-A271 974

Volume 1 of 3 Volumes:
Tabs A, B

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NOV 0 4 1993
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Technical Report D06200-2
Contract No. N00039-88-C-0065
August 1992

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

Prepared for:

Submarine Communications Project Office
Space and Naval Warfare Systems Command
Washington, D.C. 20363-5100

93-26671

Submitted by:

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IITRI

93 11 2 113

Printed in the United States of America

This report is available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1992	Annual Report, 1/91-12/91

4. TITLE AND SUBTITLE
Compilation of 1991 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program
Volume 1 of 3: Tabs A, B

5. FUNDING NUMBERS
C: N00039-88-C-0065
PE: CLIN 0004AA

6. AUTHOR(S)
See index J. E. Zapotosky, compiler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799

8. PERFORMING ORGANIZATION REPORT NUMBER
D06200-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Submarine Communications Project Office
Space and Naval Warfare Systems Command
Washington, D.C. 20363-5100

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified/Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Navy initiated studies in 1982 for possible bioelectromagnetic effects from operation of their ELF transmitters in Michigan and Wisconsin. Since then, resident biota have been monitored for effects while transmitters were operated at both intermittent low-power and continuous full-power conditions. This tenth compilation of investigator reports documents the technical progress of biological studies that were performed near the Michigan transmitter through 1991. Near the Wisconsin transmitter, similar studies were completed during 1989. To date, investigators have not found any effects on biota from either an intermittent or a fully energized transmitter

14. SUBJECT TERMS
Ecology; environmental studies; electromagnetic fields; extremely low frequency; ELF Communications System; ELF Ecological Monitoring Program

15. NUMBER OF PAGES
415

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

FOREWORD

During 1991, the Navy continued to conduct long-term studies monitoring for possible effects to biota from operation of their ELF Communications System. The Space and Naval Warfare Systems Command (SPAWAR) funded these studies through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management of monitoring studies performed by university subcontractors.

The reports compiled (Tabs A-H) in this three-volume document present the progress and findings of ongoing studies located near the Naval Radio Transmitting Facility--Republic, Michigan. At least three scientific peers reviewed each report. Study investigators considered the peer critiques prior to providing a final copy of their annual report to IITRI. These annual reports are compiled here without further change or editing by SPAWAR or IITRI. As is done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Past compilations and other program documents are listed under Tab I.

DTIC QUALITY INSPECTED 5

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: HERBACEOUS PLANT COVER AND TREE STUDIES

The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1991

SUBCONTRACT NUMBER: E06595-88-C-001

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RELEASING AUTHORITY: Wood — Rom

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INTRODUCTION

Background

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic (EM) fields cause changes in forest productivity or health. Studies initiated at control, antenna and ground treatment plots have established a baseline of data that is being used to compare various aspects of these communities before and after the antenna became operational. This approach is the most rigorous for evaluating possible effects of ELF fields on forest ecosystems. The end of the 1991 field season marks the second year of data collection under full antenna operation. This Report examines the degree of success achieved by research efforts through the 1990 and 1991 field seasons (depending on the work elemant).

Objectives

Our broad objective remains to assess the impact of ELF fields on forest productivity and health. To accomplish this, more specific objectives of the work elements are to determine the impacts of ELF electromagnetic fields on:

1) growth rates of established stands, individual hardwood trees and red pine seedlings,
2) timing of selected phenological events of trees, herbs and mycorrhizal fungi,
3) numbers and kinds of indigenous mycorrhizae on red pine seedlings,
4) nutrient levels of hardwoods and red pine,
5) foliage production in hardwoods.

The ecologically significant subject of insect and disease incidence is discussed in a related project on litter decomposition.

Ultimately, the question of whether ELF EM fields measurably impact forest communities will be answered by testing various hypotheses (Table 1) based on the results of long-term studies.

PROJECT DESIGN

Overview of Experimental Design

This study is based on a statistically rigorous design to separate possibly subtle ELF field effects on response variables from the existing natural variability caused by soil, stand and climatic factors. Consequently, to test our hypotheses, it has been imperative to directly measure both

Table 1. Critical hypotheses that are tested to fulfill the objectives of the ELF environmental monitoring program Upland Flora project.

I.	There is no difference in the magnitude or the pattern of seasonal diameter growth of hardwoods before and after the ELF antenna becomes activated.
II.	There is no difference in the magnitude of diameter growth of red pine seedlings before and after the ELF antenna becomes activated.
III.	There is no difference in the magnitude or rate of height growth of red pine seedlings before and after the ELF antenna becomes activated.
IV.	There is no difference in the rate of growth and phenological development of the herb, *Trientalis borealis* L., before and after the ELF antenna becomes activated.
V.	There is no difference in the number of different types of mycorrhizal root tips on red pine seedlings before and after the antenna becomes activated.
VI.	There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELF antenna becomes activated.
VII.	There is no difference in the foliar nutrient concentrations of northern red oak trees or red pine seedlings before and after the ELF antenna becomes activated.

plant growth and important regulators of the growth process such as tree, stand, and site factors in addition to ELF fields at the sites. Our work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypothesis (Table 2). The experimental design integrates direct measures with site variables and electromagnetic field exposure and is a common thread through nearly all studies due to the field design.

Experimental Design And Electromagnetic Exposure

At the outset of the project, it was known that the EM fields associated with the ELF system would be different at the antenna and ground locations. IITRI has measured 76 hz electric field intensities at the antenna, ground, and control sites since 1986 when antenna testing began and background 60 Hz field levels were measured at all sites in 1985. Three types of EM fields are measured: magnetic (mG), longitudinal (mV/m), and transverse (V/m).

The experimental design is best described as a split plot in space and time. Each site (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two subunits (hardwood stands and red pine (*Pinus resinosa* Ait.) plantations). These stand types comprise the treatments for the second level of the design. Each stand type is replicated three times on a site (where sites represent different levels of ELF field exposure) to control variation in non-treatment factors that may affect growth or health such as soil, stand conditions and background and treatment EM field levels. The time factor in the design is the number of years that an experiment is conducted for baseline to treatment comparisons, or the number of sampling periods in one season for year-to-year comparisons. It is necessary to account for time in the experimental design since successive measurements are made on the same plots and individual trees over a long period of time without re-randomization.

Each site follows this design with one exception. There is no hardwood stand at the ground site because required buffer strips would have resulted in the stands being too distant from the ground for significant exposure to ELF fields.

Table 2. Measurements needed for testing the critical hypotheses of the ELF environmental monitoring program Upland Flora project, the objective it is related to, and the work elements addressing the necessary measurements and analyses.

Hypothesis Number	Related Objectives	Measurements	Work Elements
I	1,2	*Weekly dendrometer band readings** climatic variables, soil nutrients, tree and stand characteristics.	1,2,3
II	1	*Annual diameter growth*, terminal bud size, plant moisture stress, microsite climatic variables, number of mycorrhizae.	1,2,3,5
III	1,2	*Weekly height growth, annual height growth*, terminal bud size, plant moisture stress, number of mycorrhizae, ambient measures.	1,2,3,5
IV	2	Periodic measures of plant dimensional variables including *leaf size* and phenological stages of *flowering, fruiting,* etc., climatic variables.	1,3
V	3	*Monthly counts of mycorrhizal root tips by type*, climatic variables, tree variables.	1,2,4
VI	5	*Periodic collections of litter, nutrient analyses*, climatical variables.	1,5
VII	4	*Periodic collections of foliage, nutrient analyses*, climatic variables.	1,2,5

*Underlined print designates response variables; others listed are covariates which are also tested for independence of ELF EM field effects.

Analysis of Covariance

Our experimental design directly controls error in the field through replications at the sites. Indirect, or statistical control, can also increase precision and remove potential sources of bias through the use of covariate analysis. This analysis uses covariates which are related to the variable of interest to remove the effects of an environmental source of variation that would otherwise contribute to experimental error. The covariate need not be a direct causal agent of the variate, but merely reflect some characteristic of the environment which also influences the variate.

Covariates under examination vary for a given response variable (Table 2). Most analyses use ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as variables computed from these data, such as air temperature degree days, soil temperature degree days and cumulative precipitation. Depending on the response variable, microsite factors are also considered. There are also factors that are more specific to the variable; for example, covariates in the analysis of red pine height growth include bud size, seedling diameter, and total height of the seedling at the beginning of the study in addition to ambient factors.

Testing for ELF EM Field Effects

From IITRI data, it is apparent that field intensities are affected by vegetative and soil factors. Also, treatment levels have not been uniform over time because of the various testing phases prior to antenna operation. Since the antenna was activated for low level testing throughout the growing seasons of 1987 and 1988 and full power operation in late 1989, hypothesis testing examines differences in response variables between these and previous years, and differences between control, antenna and ground sites in 1987 through 1990 (or 1991 depending on the work element).

The most extensive comparisons are for yearly and site within year differences. For all hypotheses, ambient and other variables are used to explain site and year differences. Comparisons between pre- and post-operational years are made, as are comparisons of relationships between sites after antenna activation, to infer if antenna operation has had a detectable effect on the response variables. For those elements where analysis of covariance is used, we test to insure that covariates are statistically independent of the EM fields and then examine whether fields explain differences for a particular response variable. If differences are apparent in the modelling effort, correlation is used to determine

whether residuals from these analyses are related to ELF fields.

Detection Limits and Statistical Power

Since each study has been peer reviewed through the years, we feel that the biological basis of each is sound and will contribute to the overall objective aimed at determining whether forest productivity or health are affected by ELF EM fields. But because of the variability inherent in ecosystem level studies and the subtle perturbations expected from ELF EM field exposure, a quantitative assessment of the level of success and precision achieved by each of the studies in the Upland Flora project is central to discussions of proposed continuation. Two different measures have been considered to make this evaluation, statistical power and detection limits.

Power is defined as the likelihood that a particular statistical test will lead to rejecting the null hypothesis if the null hypothesis is false. Exact calculation of power requires knowledge of the alpha level (Type I Error), parameters of the distribution of the variable of interest under the null hypothesis and the specification of a given alternative parameter value. In a t-test, for example, to determine power one must know the alpha level (usually 0.05 in the tests described here), the value of the test statistic under the null hypothesis (zero if the test is to determine if two means are different or not), and the degree of difference in the means which is considered biologically important (such as a ten-percent difference). The last value is the most difficult for scientists to agree upon in ecological studies because it is a matter of belief and judgement. Often, quantitative knowledge of ecological relationships is poor and scientists lack the perspective to determine whether a ten-percent difference in a parameter is ecologically significant but a five-percent difference is not. While it is possible to calculate curves showing power for a number of alternative hypotheses, one is still left with the question of how much of a difference is important. An alternative procedure which does not require the specification of this degree of difference is to do an a posteriori calculation of the detection limit.

The detection limit is the degree of difference which leads to 50-percent chance of correctly rejecting the null hypothesis (power) for a given alpha level. Use of the detection limit allows an individual reader or reviewer to evaluate the test in light of their own interpretation of what degree of difference is ecologically important. The calculation of detection limits is not exact since it is an a posteriori test; it depends on the data used in the test procedure and the procedure itself. In the tables presented in this technical summary and proposal, the detection limits

were calculated using the results from the analyses of covariance and the Student-Newman-Keuls comparison of means procedure. The detection limits are, therefore, usually conservative (larger than what may be actually detectable) since additional statistical tests which may be more sensitive to changes in system behavior, such as those utilizing models of expected behavior, are also being performed.

In summary, calculation of statistical power has the advantage of being exact, but the disadvantage for ecological studies of requiring one to specify a specific degree of change that is considered important. The calculation of detection limits has the advantage of not requiring the specification of an alternative (power is fixed at 50 percent), but the disadvantage of being an *a posteriori* calculation; therefore, it is not exact. It is our feeling that the latter quantity, the detection limit, provides information similar to statistical power, but is more suitable for ecological studies since specifications of an exact alternative hypothesis is not required.

Work Elements

The various work elements of this project were established to group similar tasks and analyses. Although data from several work elements are often used to test a single hypothesis, we retain the work element format in this report to allow the reader to easily refer to details presented in past annual reports. Each of the following sections presents a synopsis of the rationale for study, measures and analyses, and progress.

Element 1: AMBIENT MONITORING

The growth and development of a forest community or an individual in the community is directly related to the environmental factors (natural and anthropogenic) which influence the physical space that the community or individual occupies. Any study which attempts to relate the development of a population to any one of these factors must also determine and screen out the effects of other independent factors. Thus, variability in plant growth, development, or phenological events within the influence of the ELF antenna system must first be related to microclimatic and other ambient variables before the effect of a single and potentially subtle factor, such as the electromagnetic fields of the ELF antenna, can be quantified (National Research Council, 1977).

Given the overall importance of ambient factors to the Upland Flora Project, the objectives of this monitoring work element are to:

1. evaluate the natural ambient differences between the control site and the test sites.

2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.

3. select ambient variables which are independent of ELF system effects which then can be used to (1) build models to predict community growth and development and (2) supply ambient variables as covariates for community growth and development analysis.

4. evaluate possible ELF system effects on non-independent ambient variables detected through the screening process in objective 3.

Accomplishing these objectives will not only document ambient differences among sites and annual changes in these conditions but also quantify ambient variables which can be employed in the growth and development modeling in the various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic and soil relationships to other study components as discussed in the design section dealing with covariate analysis. Accomplishment of the last objective will give direct measurement of any ELF system influences on such factors as solar radiation in the understory or soil nutrient status that may be affected by overstory biomass. The initiation and schedule of each phase of the objectives are presented in Figure 1.1.

Work on the Upland Flora Project during the past seven years has indicated that soil is important to the project's

growth modeling efforts. Thus comparisons of soil chemical properties among sites and years are include in this element. The ambient monitoring element is separated into two sections, climatic monitoring and nutrient monitoring, to reflect the two distinct monitoring activities.

Climatic Monitoring

Sampling and Data Collection

System Configuration

The climatic variables being measured in the study are air temperature (30cm and 2m above the ground), soil temperature and soil moisture at depths of 5 and 10 cm, global solar radiation, relative humidity, photosynthetically active radiation (PAR), and precipitation. The configuration and placement of the sensors at the study sites have been presented in Appendix B (Table 1) of the 1985 Herbaceous Plant Growth and Tree Studies Project annual report.

Due to the location of the precipitation, relative humidity, and global solar radiation sensors measurements of these variables are considered to be independent of possible ecological changes caused by ELF electromagnetic fields. Locations of the air temperature, soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) sensors are such that they may be sensitive to ecological changes related to stand characteristics and thus by possible effects of ELF electromagnetic fields.

Air temperature, soil temperature, PAR, and relative humidity are measured every 30 minutes by a Handar, Inc. ambient monitoring platform. Global solar radiation is measured every 60 minutes, soil moisture is sampled every 3 hours, and precipitation monitored continuously. A microprocessor on board the ambient system calculates three hour averages or totals for the appropriate climatic variables. These averages and totals as well as the soil moisture and global solar radiation measurements are transmitted to the GOES East satellite every three hours and relayed to Camp Springs, Virginia. The data are transferred from Camp Springs to an IBM PC at MTU nightly.

Soil moisture subsampling procedures are performed at each site in order to more accurately measure soil moisture content over the entire area of each plot. Twenty cores are randomly taken from each plot at each site once a month. Moisture content for each depth (5 cm and 10 cm) is determined gravimetrically from a composite of the cores from a plot. These moisture contents are considered to

represent the average moisture content for a given plot for the day of core sampling.

Differences between the soil moisture content calculated from the cores and measurements from the soil moisture sensors for a given plot and day of core collection are used as an adjustment for the soil moisture readings for each plot over a monthly time interval. To eliminate any abrupt changes in estimated soil moisture contents between consecutive months which would be attributed to the monthly adjustment, the weighting equation (1.1) is used to determine the actual monthly soil moisture sensor adjustments. The equation's adjustments for a given month are weighted more heavily to the month of adjustment.

Equation 1.1 Monthly adjustment for a specific plot

$$\frac{(CSM_{(M-1)} - PSM_{(M-1)}) + 2*(CSM_{(M)} - PSM_{(M)}) + (CSM_{(M+1)} - PSM_{(M+1)})}{4}$$

CSM = Core Soil Moisture from the plot

PSM = Probe Soil Moisture from the plot

M = Month of Adjustment

M+1 = Following Month

M-1 = Previous Month

As stated in the 1986 Herbaceous Plant Cover and Tree Studies Annual Report, 1985 soil moisture measurements could not be used in any analyses. Thus the 1990 measurements were only the sixth full year of soil moisture measurement.

System Maintenance and Performance

The performance of the climatic monitoring system in 1988 was enhanced by the installation of lightning protection equipment at the sites through a cooperative effort between MTU and IITRI. Performance of the system since the installation of this equipment has improved dramatically. Downtime of the systems have been virtually eliminated by these improvements.

Data Management

Daily averages or totals, maximums, and minimums are computed for each sensor using all 3 hour measurements (eight/day) transmitted by the platforms. If less than six transmissions are received in a day for an air temperature, relative humidity, or solar radiation sensor daily statistics for that sensor are not calculated. Due to small diurnal variability in soil temperature and soil moisture the transmission limits for calculation of daily statistics for these sensors are four and two transmissions

respectively. Weekly and monthly averages or totals are then computed from these summaries.

Weekly or seven day summaries comprise the basic climatic unit used by the tree productivity study (element 2). One summary generated from the climatic information is adjusted to correspond to the weekly measurements of tree diameter or height. For example if red pine height growth and hardwood tree diameter growth was determined for the seven days from May 9 through May 15, weekly ambient summaries are also calculated for these same seven days. This insures a consistent relationship between tree productivity measurements and climatic measurement summaries. Weekly averages are considered missing and not calculated if less than four daily averages are computed from a sensor for a given seven day period. Daily climatic information is summarized in the same manner to correspond to sampling periods in each of the other project elements.

Monthly averages and totals are the basic unit used for site and year comparisons in this study element. Weekly averages and totals corresponding to seven day periods in a month are calculated from the daily climatic averages and totals (Table 1.1). These weeks are used as repeated replicate samples for each plot during each month during the growing season (refer to analysis section).

Table 1.1. Example of weekly units.

Date	Week
May 1-7	1
May 8-14	2
May 15-21	3
May 22-30	4

Missing Data Replacement

As the result of platform and sensor downtime in the past seven years, daily climatic averages or totals are estimated for days in which specific ambient observations are missing. Four hierarchical criteria and methods are used to replace the missing data. The criteria are:

1) Daily averages missing from one or two plots from a stand type of an individual site are estimated using an average of the daily summaries from the functional plots at the same stand type and site.

2) Missing daily plot averages from adjacent sites (ground and antenna) are replaced by the stand type averages from the plantation on the adjacent site if 1) there are no significant differences between the two

sites 2) there are no significant differences among plots within sites for the variable of interest. Only precipitation has met these criteria on the ground and antenna sites in the past seven years.

3) Missing daily plot averages from the ground or antenna site not estimated by the methods outlined in criteria 2 are predicted using regression equations. These equations are fitted using observed data from the sensor, plot, and site combination with the missing data as the dependent variable and the observed average daily plantation observation from the other adjacent site as the independent variable.

4) Missing plot daily average air temperatures, relative humidity, and total daily precipitation at the control site are estimated from regression equations fitted to individual observed plot averages or totals and daily observations at the Crystal Falls C#200601 weather station. This weather station is located within 9 km of the control site and is operated by the Michigan Department of Natural Resources in Crystal Falls. Missing average daily soil temperatures are estimated using regression equations fitted to stand type daily averages of air temperature at the site.

Using these techniques 95% of the missing daily averages or totals can usually be replaced. Regression equations used in the data replacement along with the related regression statistics for 1985-90 have been presented in previous Herbaceous Plant Cover and Tree Studies annual reports. The 1990 equations were presented in Appendix B (Table 1-7) of 1990 report. Improved performance of the ambient system in the past two years has eliminated any long term use of these data replacement methods. In 1990 criteria 3 was only used to estimate 3 days of missing data at the ground site during system startup in early April and 6 to 8 days of antenna information in July. Criteria 4 was used to estimate 8-10 days of information at the control site in July.

Estimates of climatic measurements obtained from criteria 1-4 are used throughout the project. Coefficients of determination as well as confidence intervals for the equations are well within acceptable limits. It is felt that the missing data replacement methods give unbiased and accurate estimates of climatic measurements and thus the variables are used in the statistical analyses in the various elements.

Data Analysis

Comparisons of site and time differences of the ambient variables generally follow a split-plot in space and time experimental design (Table 1.2). Since plot locations at one site are not related to plot locations at another site, plots are nested within sites. This nesting gives a more sensitive test of main factor effects.

The design through partitioning of variability into a number of factors (site, year, stand type etc.) and associated interactions allow a number of hypotheses to be tested. For example the site factor allows testing differences in climate between sites and year factors can quantify annual changes in climate. To determine if ELF fields are affecting ambient variables at the test sites site by year, site by stand type, and site by stand type by year interactions are used to determine if the relationship of a given ambient variable changes between the stand types or the control and test sites over time. These interaction terms can be used to quantify ELF field effects on climate by relating any temporal changes in climate to antenna preoperational and operational phases.

As mentioned previously weekly summaries are the basic unit used for statistical analysis in the element. We consider these weeks as a repeated measure on a given climatic variable. Repeated measures are multiple observations on a specific experimental unit or (in the case of climatic measurements) a specific three dimensional area. Since the observations are made on the same unit they are not independent of each other. Therefore weeks are nested in plots in the design (Table 1.2).

Comparison of ambient variables among sites, years, months, etc. were made using analysis of variance tests. Differences between specific months, years, sites, etc. were made using the Student-Newmen-Keuls (SNK) multiple range test if tests with analysis of variance indicated significant differences for the appropriate factor. Detection limits for each variable were also calculated using this multiple range test. All factors were tested at the 0.05 probability level for the ANOVA and SNK tests.

Analysis of ambient variables, which are only measured on a site level, year level, or on only one stand type, involved only a portion of the experimental design. Analysis of precipitation amounts involved site and year factors only because one sensor is located at each of the plantations. Since the ground site does not have a hardwood stand type associated with it, analyses were performed for the control vs ground site and the control vs antenna site separately with stand type dropped from the analysis for the control vs. ground site comparisons.

Table 1.2. General analysis of variance of Element 1.

Source of Variation	Sum of Squares	Mean Square	F-Ratio
SI	SS(S)	MS(S)	MS(S)/MS(E_1)
PL w SI (Error 1)	SS(E_1)	MS(E_1)	MS(E_1)/MS(E_2)
WK w PL w SI (Error 2)	SS(E_2)	MS(E_2)	
YR	SS(Y)	MS(Y)	MS(Y)/MS(E_3)
YR x SI	SS(YS)	MS(YS)	MS(YS)/MS(E_3)
YR x PLwSI (Error 3)	SS(E_3)	MS(E_3)	MS(E_3)/MS(E_4)
YR x WKwPLwSI (Error 4)	SS(E_4)	MS(E_4)	
ST	SS(T)	MS(T)	MS(T)/MS(E_5)
ST x SI	SS(TS)	MS(ST)	MS(ST)/MS(E_5)
ST x PLwSI (Error 5)	SS(E_5)	MS(E_5)	MS(E_5)/MS(E_6)
ST x WKwPLwSI (Error 6)	SS(E_6)	MS(E_6)	
MO	SS(M)	MS(M)	MS(M)/MS(E_7)
MO x SI	SS(MS)	MS(MS)	MS(M_5)/MS(E_7)
MO x PLwSI (Error 7)	SS(E_7)	MS(E_7)	MS(E_7)/MS(E_8)
MO x WKwPLwSI (Error 8)	SS(E_8)	MS(E_8)	
YR x MO	SS(YM)	MS(YM)	MS(YM)/MS(E_9)
YR x MO x SI	SS(YMS)	MS(YMS)	MS(YMS)/MS(E_9)
YR x MO x PLwSI (Error 9)	SS(E_9)	MS(E_9)	MS(E_9)/MS(E_{10})
YR x MO x WKwPLwSI(Error 10)	SS(E_{10})	MS(E_{10})	
YR x ST	SS(YT)	MS(YT)	MS(YT)/MS(E_{11})
YR x ST x SI	SS(YTS)	MS(YTS)	MS(YTS)/MS(E_{11})
YR x ST x SI (Error 11)	SS(E_{11})	MS(E_{11})	MS(E_{11})/MS(E_{12})
YR x ST x SI x WKwPLwSI(Error 12)	SS(E_{12})		
ST x MO	SS(TM)	MS(TM)	MS(TM)/MS(E_{13})
ST x MO x SI	SS(TMS)	MS(TMS)	MS(TMS)/MS(E_{13})
ST x MO x PLwSI (Error 13)	SS(E_{13})	MS(E_{13})	MS(E_{13})/MS(E_{14})
ST x MO x WKwPLwSI (Error 14)	SS(E_{14})	MS(E_{14})	
YR x ST x MO x SI	SS(YTMS)	MS(YTMS)	MS(YTMS)/MS(E_{15})
YR x ST x MO x PLwSI (Error 15)	SS(E_{15})	MS(E_{15})	MS(E_{15})/MS(E_{16})
YR x ST x MO x WKwPLwSI (Error 16)		SS(E_{16})	MS(E_{16})

```
      Site = SI, S   Within=w
Stand Type = ST, T       By=x
      Year = YR, Y
     Month = MO, M
      Plot = PL
```

Progress

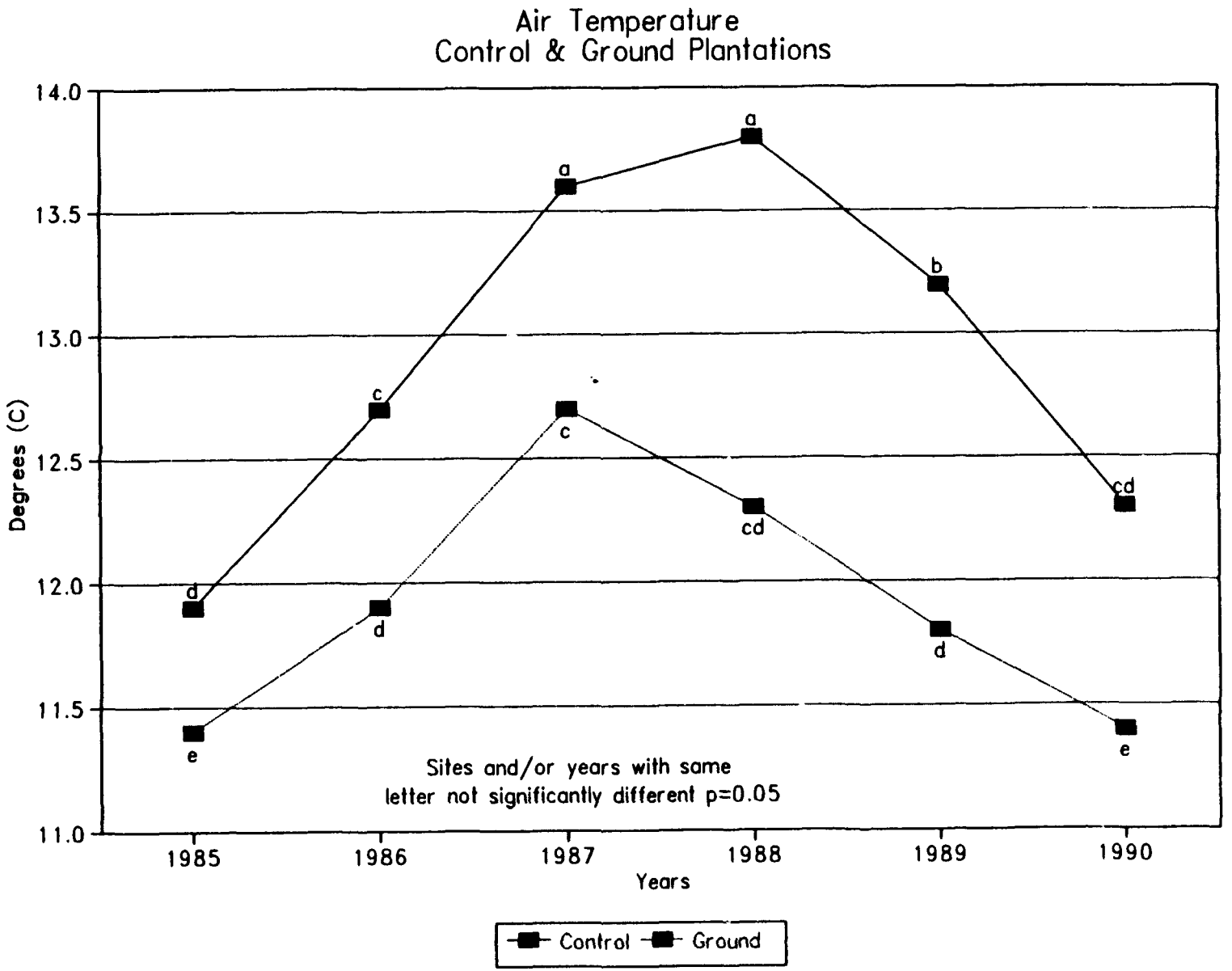
This year concludes the seventh full year of data collection by the ambient monitoring system and the second year of full operation of the ELF antenna. In previous reports summarization and statistical comparison of the ambient variables have included the most current year of measurement. However, a number of other elements in the study which use the ambient information lag one year behind in data analysis and presentation of results. Electromagnetic field strengths measured at the site are also reported from the previous but not current year. In order to be more consistent this years report includes summaries and statistical analysis of the climatic information through 1990. This years report also includes analyses to determine if the ambient variables are related to the electromagnetic fields which have been measured at the sites during 1985-1990. The objective of this effort is to determine if ambient and climatic factors are correlated to the field exposure at the sites. Significant correlations between these fields and the ambient variables would suggest that either a mechanistic or coincidental relationship exists between the measured ambient variables and ELF antenna operation. Regardless of the actual cause for such a relationship it is important to determine which variables are independent and which variables are either affected by or confounded with the ELF antenna operation. Variables which are related to ELF fields, do not meet the assumptions of independence that is necessary for inclusions as covariates in the statistical designs.

Relationships between ambient measurements and the ELF fields are determined using Pearson Product Moment Correlation Coefficients. Ambient measurements used for the correlations are the growing season averages or totals for each plot and site used for ANOVA analyses in this element. Mean magnetic field exposures (76hz) for each plot are determined by integrating the equations for each field (Appendix A) over the area of the plot. Mean longitudinal fields (76hz) for each plot and year are determined from on site measurements and isocline maps (Appendix A). The electromagnetic measurements chosen for the correlations are the 76 hz magnetic flux and 76 hz longitudinal electric fields during the EW leg operation. Transverse fields were not used for the correlations because of similarity with longitudinal fields (Appendix A).

Air Temperature (2m above the ground)

Air temperature has a substantial influence on plant physiological processes such as photosynthesis, cell division, and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1979). For any individual species given a specific period during the growing season, optimal net photosynthesis is associated with a specific range of temperatures (Waring and Schlesinger 1985). Thus differences

Figure 1.2


Air Temperature
Control & Ground Plantations
14.0
13.5
13.0
12.5
12.0
11.5
11.0
Degrees (C)
a
a
b
c
c
cd
d
d
cd
d
e
e
Sites and/or years with same
letter not significantly different p=0.05
1985
1986
1987
1988
1989
1990
Years
Control
Ground

in air temperature between the control and test sites or among study years could have significant effects on vegetation growth and development.

Site Comparisons: Average growing season air temperature during 1985-1990 was 0.7 and 1.0 ^{o}C warmer at the control plantation than at the antenna and ground plantations respectively (Table 1.3). Average air temperature during this same period was 0.8 ^{o}C warmer at the control hardwoods than at the antenna hardwoods (Table 1.3). ANOVA tests showed significantly higher temperatures at the control compared to the ground site ($p=.007$) and control compared to the antenna site ($p=.001$).

Annual Comparisons: Air temperatures in 1987 and 1988 were warmer than in any other year of the study. ANOVA tests showed significant differences in average growing season air temperatures among years for the control-ground comparisons ($p<.001$) and the control-antenna comparisons ($p<.001$). Multiple range tests ranked annual growing season air temperatures for the control and ground as follows (Table 1.3): 1988=1987>1989=1986>1990>1985. Ranking of the temperatures at the control and antenna sites were as follows (Table 1.3):1988=1987>1989=1986>1990>1985.

Site by Year Comparisons: ANOVA test again in 1990 showed significant site by year interactions for the control vs ground ($p=.020$) site comparisons but not the control vs antenna site comparisons ($p=.433$). Figure 1.2 shows the mean air temperature during the growing season at the control and ground plantations during 1985-1990. Differences in air temperature between the two sites increased from a low in 1985 of 0.5 ^{o}C to a high of 1.5 ^{o}C in 1988. Starting in 1989 these differences have been decreasing and in 1990 the control plantation was only 0.9^{o}C warmer than the ground plantation (Table 1.3). Differences in air temperature at the control and antenna plantations show a similar trend but the change in temperature during the years has not been as great. Differences in air temperature between the control and antenna hardwoods in contrast to the plantations have remained extremely stable during the six year study period (Table 1.3). However, site by stand type by year interactions have not been found to significantly differ ($p=.193$).

Comparisons of the average air temperature at the plantations and hardwood stands at the control and antenna sites during 1985-1990, revealed that differences in air temperatures of these two stand types increased beginning in 1987 (Figure 1.3). Differences in temperatures between the two stand types were significant ($p=.05$) in 1988 and 1989 but by 1990 differences again were not significant. In previous reports the increased temperatures of the plantations compared

Figure 1.3

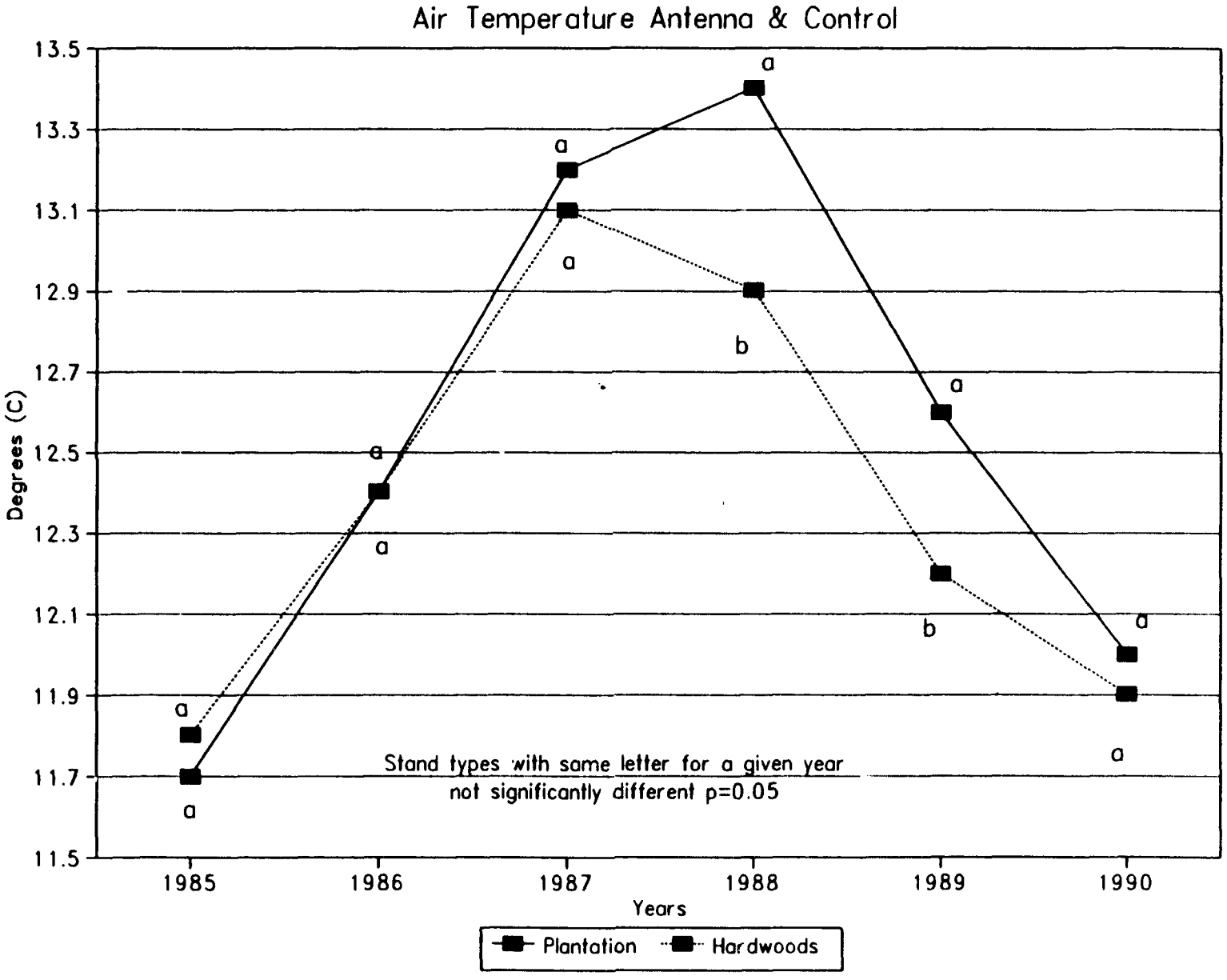

Air Temperature Antenna & Control
13.5
13.3
13.1
12.9
12.7
12.5
12.3
12.1
11.9
11.7
11.5
Degrees (C)
1985
1986
1987
1988
1989
1990
Years
Stand types with same letter for a given year
not significantly different p=0.05
Plantation
Hardwoods

Table 1.3 Comparison of mean air temperature (°C) 2 m above ground during the 1985-90 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	11.4	11.5	11.9	0.5	0.4
1986	11.9	12.1	12.7	0.8	0.6
1987	12.7	12.9	13.6	0.9	0.7
1988	12.3	12.9	13.8	1.5	0.9
1989	11.8	12.1	13.2	1.4	1.1
1990	11.4	11.7	12.3	0.9	0.6
Ave.	11.9	12.2	12.9	1.0	0.7
			Hardwoods		
1985		11.4	12.3		0.9
1986		12.0	12.9		0.9
1987		12.7	13.5		0.8
1988		12.5	13.3		0.8
1989		11.8	12.5		0.7
1990		11.5	12.3		0.8
Ave.		12.0	12.8		0.8

1985-1990 MEAN DAILY AIR TEMPERATURE (C°)

Site Comparisons

Control	Ground
12.9 a	11.9 b

Control	Antenna
12.9 a	12.1 b

Annual Comparisons

	Control & Ground	Control & Antenna
1985	11.7 c	11.8 d
1986	12.3 c	12.4 b
1987	13.1 a	13.2 a
1988	13.1 a	13.1 a
1989	12.5 b	12.4 b
1990	11.9 c	12.0 c

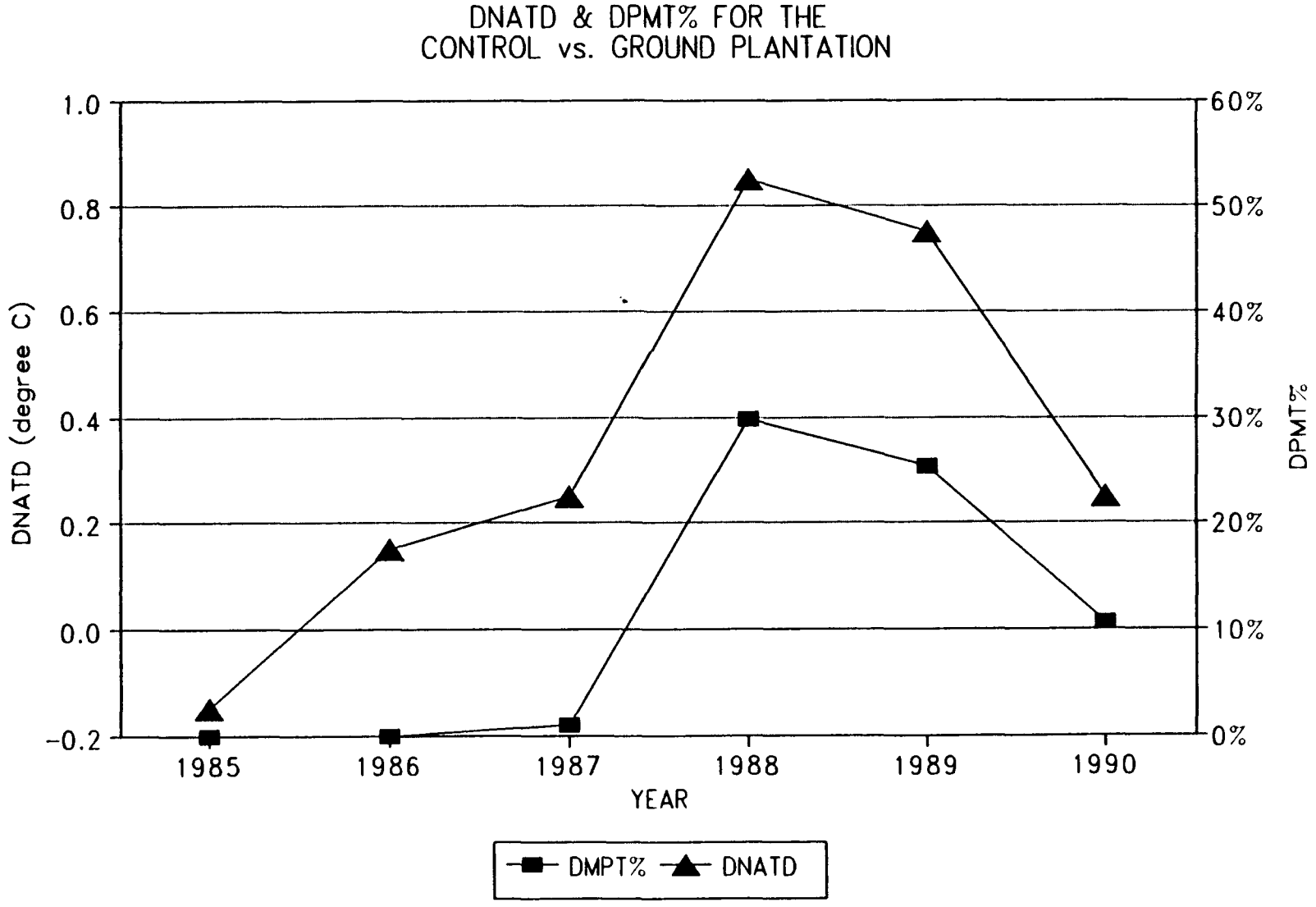
[1]Sites or years with the same letters for a specific site combination not significantly different at p=0.05

to the hardwood stands and the increased temperatures of the control plantation compared to the test plantations have been shown to be a related to the growth of the red pine. As the canopy of the red pine approached the height of the air temperature sensors in the plantations, air temperature was found to increase in the plantations relative to the hardwood stands. Air temperature at the control plantation, which has had the greatest height growth, increased to a greater extent than the air temperature at the test plantations. The decreased differences in the temperature between the two stand types and the decreased differences in the temperatures between the control and test plantations during 1990 implies that either, the canopies of the red pine at the control site are beginning to grow above the sensor level and thus their impact on air temperature in relation to initial plantation conditions is decreasing and/or, 2) the height of the canopy at the test plantations has increased to such an extent that these canopies are having a greater effect on air temperature than in previous years.

In order to evaluate the relationships between canopy heights and air temperature, an average air temperature difference between the control and each test plantation was computed using the 1985 and 1986 observations. This was considered to be the normal difference in air temperature (NDAT) among sites before the alteration by the planted trees. A departure from this normal air temperature difference (DNATD) was then computed by subtracting the NDAT from the observed air temperature differences (Table 1.3) for each year of the study. The percentage of permanently marked red pine with total heights between 1.25 and 2.75 m (Element 2) were then determined for the plantation of each site and year of the study. This height interval was considered to be representative of the tree height at which the tree canopy could effect air temperature at the 2 m sensor level. Differences between the percentage of the permanently marked trees in this height interval (DPMT%) for control and each test site (ex. Control-Ground) were determined. The DNATD and DPMT% were plotted for each year of the study. Comparisons of these values for the control and ground sites (Figure 1.4) shows a direct relationship between the differences in air temperature and differences in the percentage of trees in the designated height class. The reduction in the differences in air temperature between the control and ground plantations in 1990 appeared to be caused by the reduced differences in the percentage of trees in the specific height interval. A similar relationship was found when comparing data from the control and antenna sites. These graphs support the conclusion that the red pine canopy is altering the air temperature at the 2m sensor height and that the differing growth rates at the sites are contributing to the annual changes in air temperature among control and test plantations.

Summary: As in previous years analyses, air temperature at the control site was found to be significantly higher than

Figure 1.4


DNATD & DPMT% FOR THE
CONTROL vs. GROUND PLANTATION
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
DNATD (degree C)
60%
50%
40%
30%
20%
10%
0%
DPMT%
1985
1986
1987
1988
1989
1990
YEAR
DMPT%
DNATD

at the test sites. This indicates that differences in air temperatures among sites are in part due to differences in regional climate or local topography among sites. Differences in air temperature at the control and antenna hardwood stands have remained extremely stable over the six year analysis period. However, differences between air temperatures in the control and test plantations have varied with differences increasing from 1986-1989 and then decreasing in 1990. These changes in air temperature are related to the increasing influence of the planted red pine on air temperature at the 2m sensor height and the differences in the height growth of the red pine among sites. There does not appear to be any direct effect of ELF on air temperature unless the ELF antenna operation has altered the height growth of the trees in the plantation. Until it has been determined whether height growth has altered the growth of the trees at the test sites, the effects of antenna operation can not be fully determined.

Soil Temperature

Soil temperature like air temperature has a direct influence on plant physiological processes such as cell division and elongation. However soil temperature also indirectly influences plant growth by affecting permeability of roots and thus water uptake (Kramer 1983), biological decomposition and availability of nutrients (Brady 1974). Climatic conditions or stand characteristics such as insolation, air temperature, and precipitation as well as soil characteristics are the main factors controlling soil temperatures. Thus possible changes in vegetation or soil properties (organic matter content etc.) due to ELF antenna operation could have a major effect on soil temperature. These effects would appear to be more dramatic in the hardwood stands where microclimate is influenced to greater degree by vegetation than it is in the younger plantation stands.

Soil Temperature (depth of 5 cm)

Site Comparisons: Differences in mean soil temperatures (5cm) at the control and test plantations during the growing season have been less or equal to $0.5^{o}C$ during each year of the study except 1989. The mean daily soil temperature (5 cm) during the growing season at the control was consistently warmer than or equal to the soil temperature at the ground plantation during each year of the study. However, during a number of years, soil temperatures (5cm) were cooler at the control than at the antenna plantation (Table 1.4). Unlike the plantations, soil temperatures in the control hardwoods were consistently warmer than in the antenna hardwoods each year of the study. No significant differences in soil temperatures (5cm) were found between the control and ground sites ($p=.116$) or the control and antenna sites ($p=.189$)

Table 1.4 Comparison of mean soil temperature (°C) at a depth of 5 cm during the 1985-90 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.5	12.9	12.5	0.0	-0.4
1986	13.3	13.5	13.5	0.2	0.0
1987	13.4	13.7	13.6	0.2	-0.1
1988	13.2	13.5	13.7	0.5	0.2
1989	12.3	12.6	13.2	0.9	0.6
1990	12.2	12.7	12.6	0.4	-0.1
Ave.	12.8	13.2	13.2	0.4	0.0

Hardwoods

1985	10.1	10.8		0.7
1986	11.2	11.7		0.5
1987	11.8	12.3		0.5
1988	11.2	11.6		0.4
1989	10.6	11.1		0.7
1990	10.7	11.1		0.4
Ave.	10.9	11.4		0.5

Site Comparison

Control	Ground
13.2 a[1]	12.8 a

Control	Antenna
12.3 a	12.1 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.5 b	11.6 d
1986	13.4 a	12.5 b
1987	13.6 a	12.9 a
1988	13.5 a	12.5 b
1989	12.7 b	11.9 c
1990	12.4 b	11.8 cd

[1]Sites or years with the same letters for a specific site combination not significantly different at p=0.05

indicating that observed differences in soil temperature among sites is not greater than the spatial variation in soil temperature (5 cm) within sites.

Annual Comparisons: Annual variation in mean growing season soil temperatures (5 cm) during 1985-1990 was 1.2 ^{o}C for the control vs ground comparisons and 1.3 ^{o}C for the control vs. antenna comparison. Annual differences in soil temperature (5 cm) were significant ($p=<.001$) for both comparisons. Multiple range tests showed soil temperatures (5cm) during 1986-1989 to be greater than during 1985, 1989, or 1990 for the control vs ground comparisons. Mean annual soil temperatures (5 cm) for the control vs antenna comparison were ranked in a similar fashion (Table 1.4)

Site by Year Comparisons: Although differences between the soil temperatures at the control and test site plantations were greater in 1988 and 1989 than any other year (Table 1.4) site by year interactions were not significant for the control vs. ground ($p=.077$) or the control vs. antenna ($p=.497$) comparisons. As noted previously, the soil temperature (5 cm) at the control hardwoods have been consistently warmer than at the antenna hardwoods during each year of the study, while soil temperatures (5 cm) at the control plantations were neither consistently warmer nor cooler than at the antenna plantation. None the less site by stand type interactions ($p=.129$) and site by stand type by year interactions ($p=.563$) were not found to be significant. Although the increased soil temperature at the control plantations relative to the test plantations during 1988 and 1989 were consistent with the higher air temperatures in the control plantation during this period, statistical comparisons have indicated that the increased soil temperatures during 1988 and 1989 were not greater than the temporal or spatial variation in these stand types.

Soil Temperature (depth 10 cm)

Site Comparisons: Average soil temperatures (10 cm) at the control site were within 0.7^{o}C and 0.6^{o}C of the average soil temperatures (10 cm) at the test site plantations and hardwoods respectively during the entire study period (Table 1.5). As in previous years soil temperature (10 cm) was not significantly different between the control and ground ($p=.207$) or the control and antenna sites ($p=.150$).

Annual Comparisons: ANOVA tests indicated significant differences ($p<.001$) in soil temperature (10 cm) for all site comparisons. Rankings of annual soil temperature at a depth of 10cm were similar to rankings of annual soil temperature at a depth of 5cm. For both site comparisons 1986-1988 temperatures were significantly greater than 1985, 1989, and 1990 temperatures (Table 1.5).

Table 1.5 Comparison of soil temperature (10 cm) during the 1985-90 growing seasons (April-Oct).

Plantation

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	12.2	12.6	12.4	0.2	-0.2
1986	13.0	13.4	13.3	0.3	-0.1
1987	13.2	13.5	13.6	0.4	0.1
1988	13.3	13.2	13.2	-0.1	0.0
1989	12.0	12.5	12.7	0.7	0.2
1990	11.7	12.4	11.9	0.2	-0.5
Ave.	12.6	12.9	12.9	0.3	0.0

Hardwoods

1985	10.1	10.7		0.6
1986	10.9	11.4		0.5
1987	11.7	11.5		-0.2
1988	11.0	11.3		0.3
1989	10.3	10.9		0.6
1990	10.4	10.9		0.5
Ave.	10.7	11.1		0.4

Site Comparison

Control	Ground
12.9 a	12.6 a

Control	Antenna
12.0 a	11.8 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	12.3 b	11.4 c
1986	13.1 a	12.3 b
1987	13.4 a	12.6 a
1988	13.3 a	12.2 b
1989	12.3 b	11.6 c
1990	11.8 c	11.4 c

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

Site by Year Comparisons: Site by year interactions were not significant for either the control vs. ground (p=.303) or the control vs. antenna (p=.448) comparisons. Site by stand type (p=.226) and site by stand type by year (p=.264) interactions were also not significant for the control vs. antenna comparisons. These results demonstrate that the relationships in soil temperature at a depth of 10 cm among the sites and between stand types have remained relatively stable over the duration of the study.

Summary: Currently there has been no indication that the ELF fields have affected the soil temperatures (5 cm and 10 cm) at the test sites. This conclusion is based on : 1) differences between sites are not significant at this time (p=.05), 2) although differences between years exist, no significant site by year interactions have been found and 3) site by stand type by year interactions also did not significantly differed. Although the soil temperatures at this time do not indicate any ELF field effects, differences in soil temperatures at a depth of 5 cm between the control and test plantations during 1988-1990 have shown trends similar to observations of air temperature. These changes in soil temperature like air temperate are most likely related to the increased occupancy of red pine at the plantations and the differences in the productivity of the plantations at the control and test sites.

Soil Moisture

The amount and availability of water is a key factor in determining forest site productivity. The importance of water to plant growth should not be underestimated since almost all plant processes are influenced by the supply of water (Kramer 1983). Water in the soil is the primary media for transportation of nutrients within plants and is a reagent in photosynthesis. Apical and radial growth of trees have been shown to be highly correlated to soil water supplies (Zahner 1968).

Soil moisture is measured in the field and expressed as a percent of the dry soil weight at a given depth. Although moisture content gives a valuable measurement of the amount of water contained in the soil, it does not reflect to what degree plants can utilize this water. The tension at which water is held in the soil or soil water potential determines the availability of water to plants.

Given a specific moisture content, the availability of water can vary depending on soil characteristics. Thus soil water potential may give a more sensitive estimate of moisture relationships among the sites and years with respect to vegetation growth and productivity. Soil water potential values were estimated from equations relating soil moisture content at each plot to soil water potential (Appendix C 1987 Herbaceous Plant Cover and Tree Studies Annual Report). These

Table 1.6 Comparison of soil moisture content (%) and soil water potential(-Mpa) at a depth of 5 cm during the 1986-90 growing seasons (April-Oct).

Plantation

	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa
1986	13.2	.024	9.2	.022	16.0	.013	2.8	-.011	6.8	-.009
1987	13.6	.022	11.3	.013	13.5	.018	-0.1	-.004	2.2	.005
1988	11.8	.029	11.3	.016	12.9	.024	1.1	-.005	1.6	.008
1989	13.0	.018	10.9	.014	14.2	.020	1.2	.002	3.4	.006
1990	16.6	.015	13.7	.009	18.9	.010	2.3	-.005	5.2	.001
Ave.	13.6	.022	11.3	.015	15.1	.017	1.5	-.005	4.2	.002
					Hardwoods					
1986			10.4	.024	14.1	.024			3.7	.000
1987			10.8	.023	10.9	.031			0.1	.008
1988			9.5	.026	10.6	.046			1.1	.020
1989			9.5	.023	11.2	.046			1.7	.023
1990			12.6	.010	16.2	.013			3.6	.003
Ave.			10.6	.021	12.6	.030			2.0	.009

Site Comparison

	Control	Ground
Moisture Content	15.1 a[1]	13.6 b
Soil Water Pot.	.017 a[2]	.022 a
	Control	**Antenna**
Moisture Content	13.9 a	11.0 b
Soil Water Pot.	.024 b	.018 a

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-Mpa	%	-Mpa
1986	14.6 b	.018 b	12.4 b	.020 b
1987	13.6 b	.020 b	11.6 c	.021 b
1988	12.3 c	.027 b	11.1 c	.026 b
1989	13.6 b	.018 b	11.4 c	.024 b
1990	17.8 a	.012 a	15.4 a	.011 a

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

[2]ANOVA and multiple range tests of soil water potential performed on transformed (inverse natural log) data

equations were then applied to daily average soil moisture content at each depth at each plot.

Soil Moisture Status(depth 5 cm)

Site Comparisons: Soil moisture content (5 cm) for all years except 1987 was greater at the control than at the test sites (Table 1.6). ANOVA tests indicated that significantly higher soil moisture contents at the control than at either the ground ($p=.024$) or antenna ($p<.001$) sites. Average soil moisture content (5 cm) during 1986-1990 was 1.5% and 2.9% greater at the control than at the ground and antenna sites respectively (Table 1.6). Differences in moisture content of the control and antenna sites is related to the differences in the water holding capacity of these two sites (Table 1.7). Water holding capacity of the soils in the control plantation and hardwoods are respectively 90% and 37% greater than the water holding capacity of the soils in the antenna plantation and hardwoods. It appears that the differences in water holding capacity of the soils in the control and ground plantations are minimal and may not contribute to the differences in moisture content at these two sites.

Table 1.7. Water holding capacity of the mineral soil to a depth of 15cm at each site and stand type

	g water/m^2 soil	
	Plantation	Hardwood
Ground	240.9	
Antenna	125.9 b	188.3 a
Control	239.2 a	257.5 a

[1] Stand types with the same letters for a specific site are not significantly different at $p=0.05$

The site and stand type interaction was also found to be significant for soil moisture content (5 cm). Multiple range tests showed significantly ($p=.05$) higher moisture content of surface soil in the control plantation than in the control hardwoods. However, differences between the two stand types at the antenna were not significant ($p=.05$). The higher soil moisture contents observed at the control plantation compared

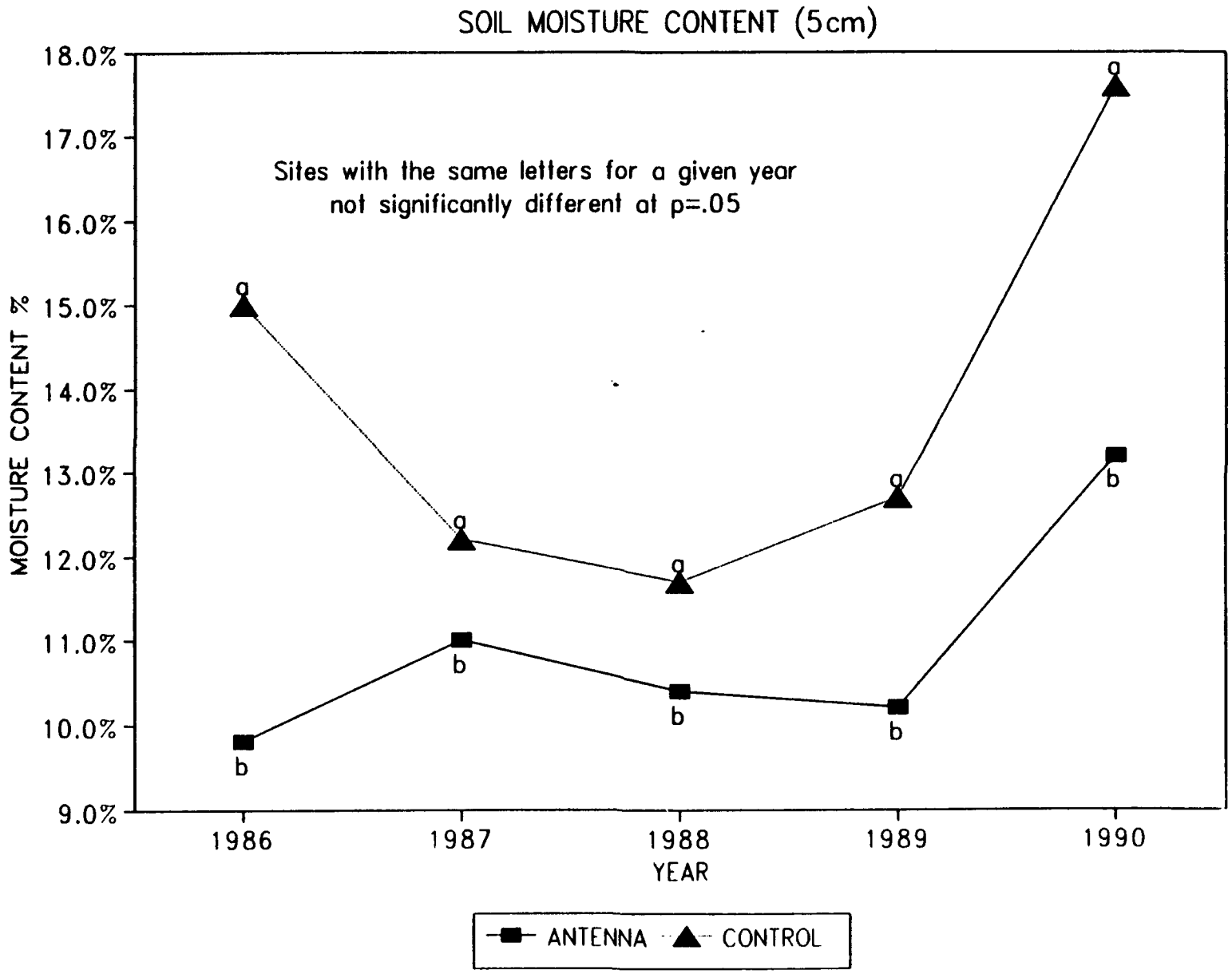
to the hardwoods is a result of the lower evapotranspiration of the plantation. At the antenna site evapotranspiration of the plantation is also lower than the hardwood stand and moisture content should also be higher in the plantation than the hardwoods. However, the water holding capacity of the soils in the plantation is significantly lower than the soils in the hardwood stand (Table 1.7) there by eliminating any potential differences in moisture content of the soils due to differing levels of evapotranspiration.

Differences in soil water potential between the sites were not found to be significant (p=.571) for the control vs. ground comparison but were significant for the control vs. antenna comparison (p=.012). Although soil moisture content was greater at the control site than at the antenna site, soil water potential was lower (more negative) at the control compared to the antenna site indicating a higher availability but not a higher amount of water at the antenna compared to the control.

Annual Comparisons: Differences in soil moisture content (5cm) and soil water potential (5 cm) were significant (p<.001) among years for both the control vs. ground and control vs. antenna comparisons. Soil moisture content (5 cm) and soil water potential (5 cm) were significantly higher (p=.05) in 1990 than in any other year of the study. The higher moisture contents and water potentials in 1990 can be attributed to relatively high levels of precipitation, a very uniform distribution of precipitation, and low levels of evapotranspiration due to below normal air temperatures during the growing season (see precipitation and air temperature sections).

Site by Year Comparisons: Soil moisture content (5 cm) site by year interactions were significant for the control vs. antenna comparison (<.001) but not the control vs. ground comparison (p=.234). Moisture content (Figure 1.5) was significantly higher (p=.05) at the control than at the antenna site during each year of the study. However, differences in moisture contents (5cm) during 1986 and 1989 were greater than during 1987-1989. In 1989 differences appeared to be greater due to the overall higher moisture contents at the sites. However, the moisture contents during 1986 were similar to moisture contents in 1987-1989. The greater differences in soil moisture content during 1986 may be an artifact of system malfunctions which took place during that year. In July of 1986 the control platform was struck by lightning and was inoperable for approximately 26 days. During this time moisture measurements at the site were not taken and could not be estimated. The antenna platform was then used to replace the control platform and soil moisture content at the antenna was calculated from soil moisture contents at the ground. The high soil moisture content during this year may be a result of the missing information at the control during a period of normally low moisture content.

Figure 1.5


SOIL MOISTURE CONTENT (5cm)
Sites with the same letters for a given year
not significantly different at p=.05
MOISTURE CONTENT %
18.0%
17.0%
16.0%
15.0%
14.0%
13.0%
12.0%
11.0%
10.0%
9.0%
a
a
a
a
a
b
b
b
b
b
1986
1987
1988
1989
1990
YEAR
ANTENNA
CONTROL

Soil water potential comparisons yielded similar results as those for soil moisture content. Site by year interactions were significant for the control vs. antenna comparison but not the control vs. ground comparison. Site by stand type by year interactions were neither significant for soil moisture content (p=.106) or soil water potential (p=.912). Although site by year interactions were significant for the control vs. antenna comparison, differences in soil moisture content (5 cm) or soil water potential (5cm) between the control and test sites have remained stable since 1987.

Soil Moisture Status (depth 10 cm)

Site Comparisons: Comparisons of soil moisture content and soil water potential (10 cm) among sites were similar to comparison of soil moisture content and water potential at depths of 5 cm. Soil moisture content (10cm) was significantly higher at the control site than at the ground site (p=.05) or antenna site (p=.005). However differences in soil water potential were not significant for the control vs ground (p=.803) or the control vs. antenna (p=.287) comparisons. Differences in soil moisture content (10 cm) between the control and antenna sites were greater than between the control and ground sites (Table 1.8). As was found for soil moisture contents at depths of 5cm, differences in soil moisture content among sites at depths of 10 cm were related to the differences in water holding capacities of the soil among sites.

Control vs. antenna site by stand type interactions were significant (p=.051) for soil moisture content (10 cm). Differences among stand types of the two sites were similar to those found for moisture contents at 5cm and appeared to be related to the differences in water holding capacities at the antenna plantation and hardwood stand types. Soil water potential (10 cm) site by stand type interactions were not significant (p=.754) for this comparison.

Annual Comparisons: Moisture content and soil water potential at depths of 10cm were significantly higher (p=.05) during 1990 than in any other year of the study for the control vs. antenna comparison (Table 1.8). Moisture content (10 cm) for the control vs. ground comparison was also significantly higher in 1990 than in 1988 or 1989. Both soil moisture content and water potential (10cm) was at the lowest levels in 1988.

Site by Year Comparisons: ANOVA tests of soil moisture content (10cm) showed significant site by year interactions for the control vs. ground comparison (p=.003) but not the control vs. antenna comparison (p=.064). The significant interaction for the control and ground comparison appears to be related to the moisture contents at the two sites during 1990. Average moisture content in both the control and antenna sites were higher in 1990 than in 1989 (Table 1.8).

Table 1.8 Comparison of soil moisture content (%) and soil water potential(-Mpa) at a depth of 10 cm during the 1986-90 growing seasons (April-Oct).

Plantation

	Ground		Antenna		Control		Control-Ground		Control-Antenna	
	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa	%	-Mpa
1986	15.2	.018	9.2	.018	14.6	.017	-0.6	-.001	5.4	-.001
1987	14.2	.016	9.8	.014	15.1	.014	0.9	-.002	5.3	.000
1988	12.9	.021	10.3	.018	14.4	.019	1.5	-.003	4.1	.001
1989	14.0	.016	10.7	.013	14.4	.020	1.4	.004	3.7	.007
1990	13.4	.018	12.1	.009	18.4	.009	5.0	-.009	6.3	.000
Ave.	13.9	.018	10.4	.014	15.4	.016	1.3	-.002	5.0	.002
					Hardwoods					
1986			10.0	.023	12.6	.025			2.6	.002
1987			11.2	.022	12.7	.021			1.5	-.001
1988			10.5	.019	12.8	.021			2.3	.002
1989			9.8	.022	11.1	.031			1.3	.009
1990			12.5	.010	15.5	.012			3.0	.002
Ave.			10.8	.019	12.9	.022			2.1	.003

Site Comparison

	Control	Ground
Moisture Content	15.4 a[1]	13.9 b
Soil Water Pot.	.016 a[2]	.018 a

	Control	Antenna
Moisture Content	14.1 a	10.6 b
Soil Water Pot.	.019 a	.018 a

Annual Comparison

	Control & Ground		Control & Antenna	
	%	-Mpa	%	-Mpa
1986	14.9 ab	.017 ab	11.6 b	.020 b
1987	14.7 ab	.018 ab	12.2 b	.017 b
1988	13.6 c	.021 b	12.0 b	.019 b
1989	14.2 bc	.023 ab	11.5 b	.020 b
1990	16.0 a	.014 a	14.6 a	.010 a

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

[2]ANOVA and multiple range tests of soil water potential performed on transformed (inverse natural log) data

However, average moisture content during 1990 at the ground site was lower than in 1989. As shown in Table 1.6, average moisture content at a depth of 5cm at the three sites was higher in 1990 than in 1989. Thus the decreased soil moisture contents in 1990 at the ground site appear to be an anomaly which is related to the inherent precision of the soil moisture sensors rather than ELF antenna operation.

Site by stand type by year interactions were not significant for either soil moisture content ($p=.651$) or soil water potential ($p=.902$) at a depth of 10cm. These results indicate that the relationships of these parameters between the two stand types have remained stable over the duration of the study. Differences in the moisture content of the stand types at the two sites, as noted by the significant site by stand type interactions, has not fluctuated during the five year measurement period. The lack of any significant annual variation in this relationship supports the conclusion that differences in the moisture content of the two stand types at the control and antenna sites is related to the differences in the soil physical characteristics.

Summary: At this time there has been no detectable effects of EM fields on soil moisture content and soil water potential at the test sites. This conclusion is based on the following results and observations: 1) moisture status although significantly different among sites and years show no consistent trends related to increasing levels of ELF antenna operation, 2) changes in the relationship of soil moisture regimes among the sites during the study period appear to be related to climatic factors such as precipitation and temperature rather than ELF field effects, 3) although differences in soil moisture regimes of the two stand types are not consistent at the control and antenna site, these differences are related to the soil physical characteristics and have remained stable over the duration of the study.

Precipitation

The amount of precipitation and the distribution of precipitation over time are two primary factors controlling availability of water for plant growth. Thus precipitation is an important factor in the climatic monitoring program.

Site Comparisons: Differences in the total amount and distribution of precipitation has not dramatically differed among the three sites during 1985-1990 study period (Figure 1.6). During this period the ground and antenna sites respectively received 4.71 cm and 5.05 cm more precipitation during the growing season than did the control site. The majority of this difference occurs during July and August (Figure 1.7). During these two months the ground and antenna site on the average have receive 3.96 cm of precipitation than the control.

Figure 1.6

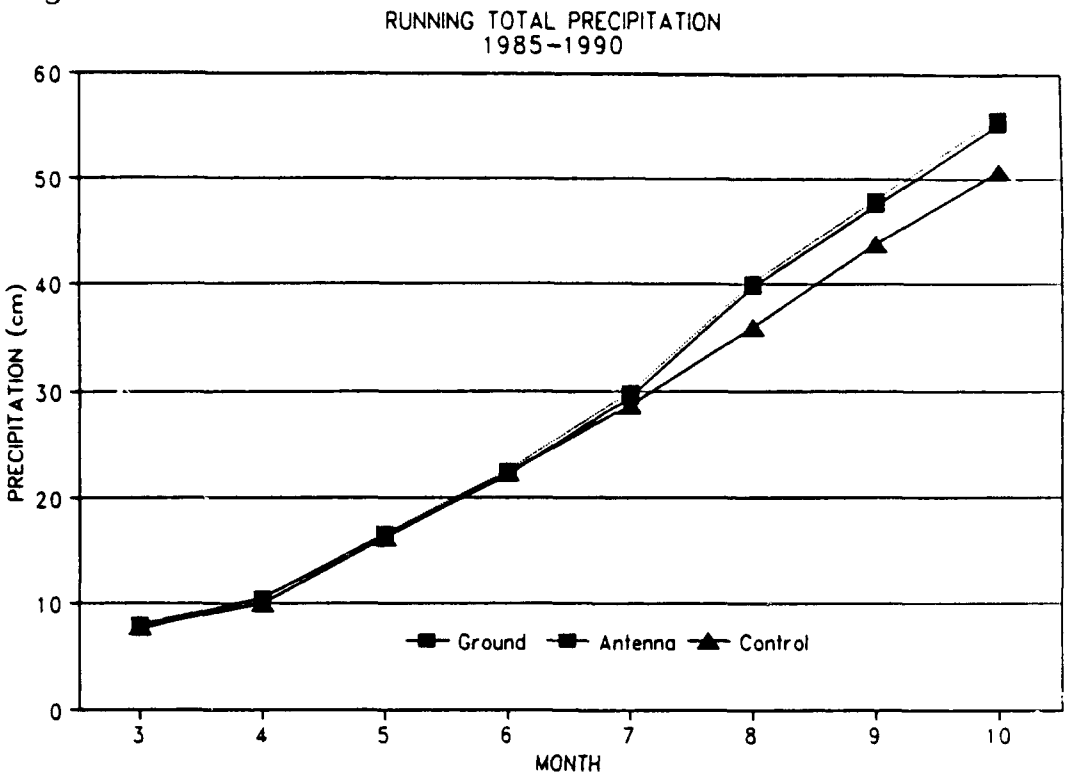
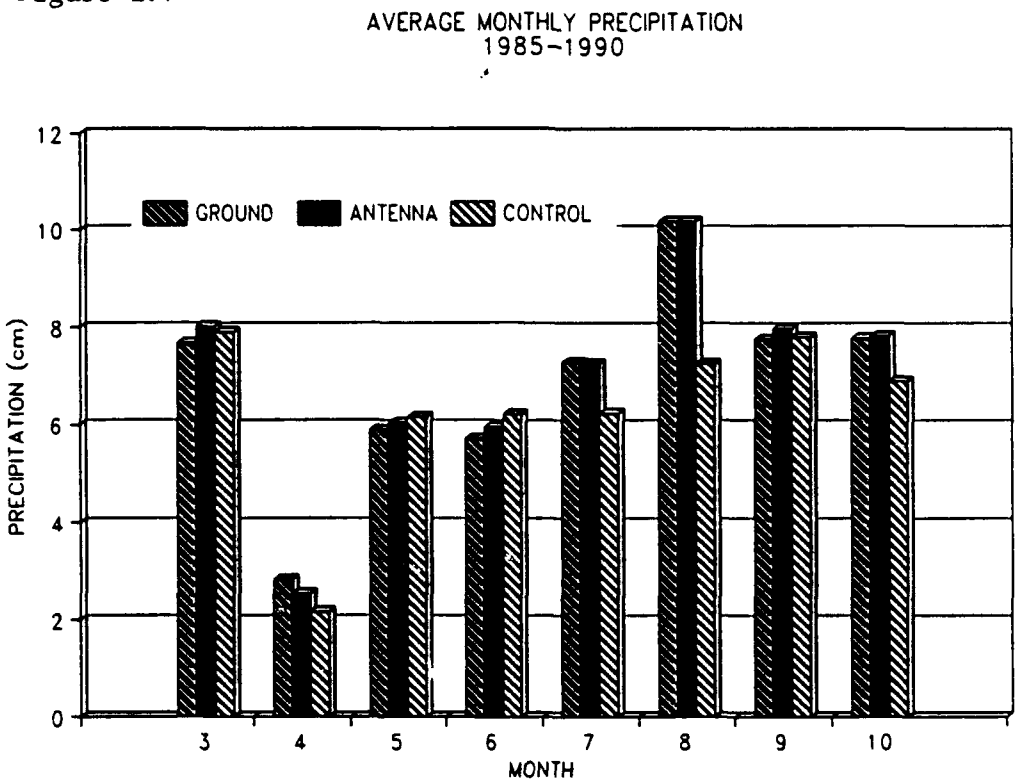


Figure 1.7



Although the test sites have received approximately 10% more precipitation than the control, differences in the weekly precipitation amounts were not significant for either the control vs. ground comparison (p=.441) or the control vs. antenna comparison (p=.409).

Annual Comparisons: Annual variation in the average weekly amount of precipitation is much greater than the variation in precipitation among sites (Table 1.9). Almost 1 cm/week more precipitation fell during 1985 than in 1986. ANOVA test showed significant differences in the average weekly precipitation amounts for the control vs. antenna comparison (p=.044) but not the control vs. ground comparison (p=.058). Differences between years at the p=.05 level could not be separated by the multiple range test employed. However

Table 1.9 Comparison average weekly precipitation amounts (cm) during the 1985-90 growing seasons (April-Oct).

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1985	2.41	2.46	1.97	-0.44	-0.49
1986	1.25	1.18	1.26	0.01	0.08
1987	1.78	1.87	1.78	0.00	-0.09
1988	1.80	1.77	1.49	-0.31	-0.28
1989	1.48	1.40	0.98	-0.50	-0.42
1990	1.60	1.72	1.80	0.20	0.09
Ave.	1.72	1.73	1.55	-0.17	-0.18

Site Comparison

Control	Ground
1.55 a[1]	1.72 a

Control	Antenna
1.55 a	1.73 a

Annual Comparison

	Control & Ground	Control & Antenna
1985	2.22 a	2.19 a
1986	1.25 a	1.22 a
1987	1.82 a	1.78 a
1988	1.63 a	1.65 a
1989	1.23 a	1.19 a
1990	1.70 a	1.76 a

[1]Sites or years with the same letters for a specific site combination are not significantly different at p=0.05

comparisons of average weekly precipitation in Table 1.9 would suggest that the amount of precipitation in 1985 was significantly greater than precipitation in 1986 or 1989.

Site by Year Comparisons: Site by year interactions were neither significant for the control vs. ground comparison (p=.892) nor the control vs. antenna comparison (p.943). Within the range of detection limits for these analyses (Table 1.14, 1.15), it does not appear that the annual variation in precipitation among sites has differed during the study period.

Summary: ANOVA tests have not indicated any significant differences in weekly precipitation among sites during the entire study period as a whole or during any single year of the study. However, the sensitivity of these tests are limit due to their high detection limits. The location of the precipitation sensors above the canopy of the plantation would eliminate any possible ELF field effects on this climatic parameter.

Global Solar Radiation

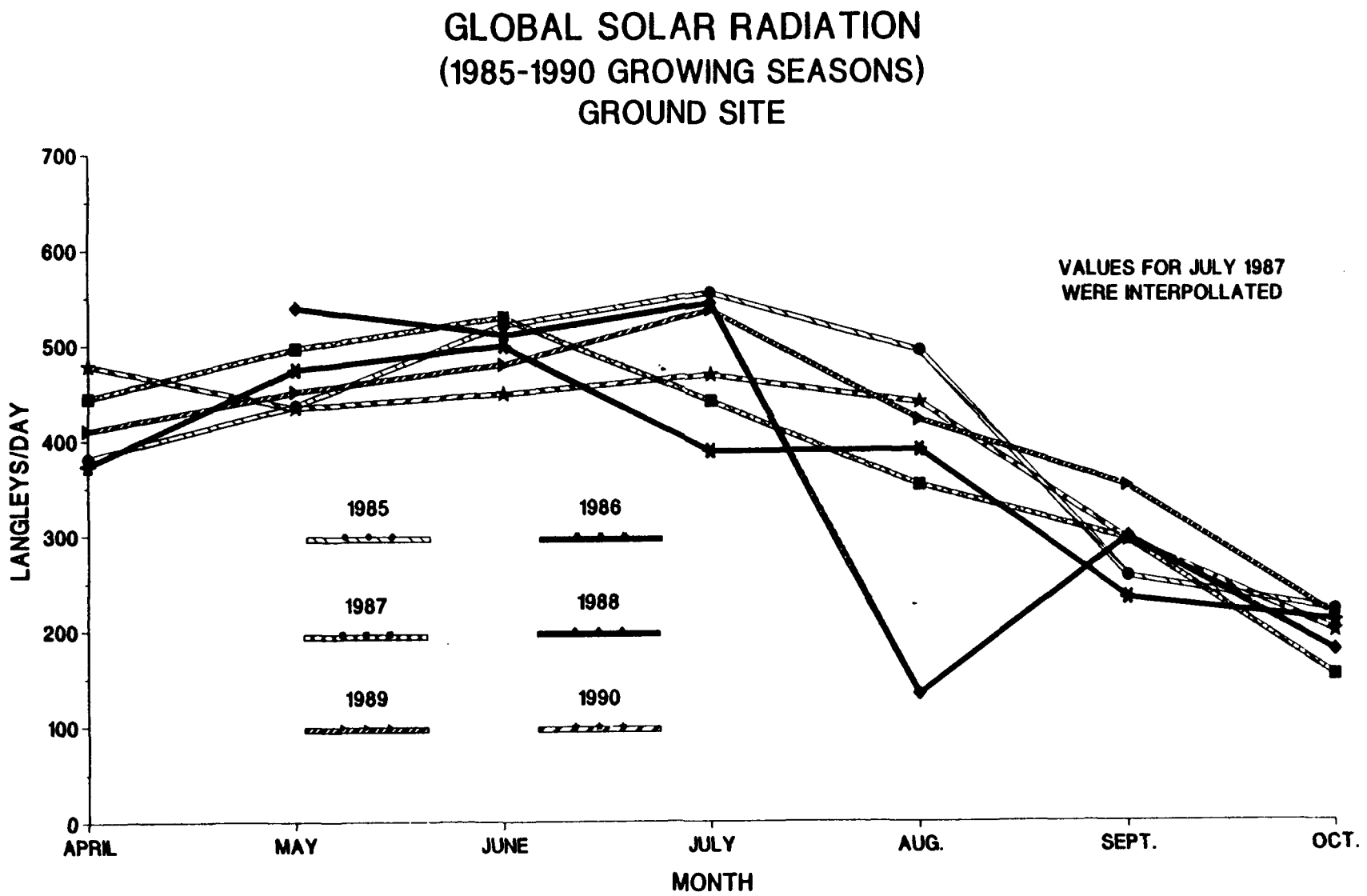
Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus solar radiation is continually monitored at the study sites.

Comparisons of global solar radiation did not include July of 1987 or April of 1988. Data from July of 1987 was not available due to the lightning strike at the ground site and the sensor was being calibrated during April of 1988. Thus it was felt that a more suitable comparison of yearly information could be made if April and July were excluded from the analyses.

Annual Comparisons: Comparisons of global solar radiation are only performed for May, June, August, September, and October measurements due to sensor failure in July of 1987 and sensor calibration in April of 1988. Measurements of global solar radiation in August of 1988 were low because 16 days of measurements were missing due to a computer failure (Figure 1.8). Average global solar radiation during 1990 was 363.5 Langleys/day (Table 1.10). Differences in average daily global solar radiation among years were not significant (p=.902). Figure 1.8 shows that variation of global radiation within years are much greater than the variation among years.

Summary: Average daily global solar radiation has not been found to significantly differ in any of the analysis to date. Detection levels (Table 1.14) for this variable are relatively high and do not afford an extremely sensitive statistical comparison of the annual variation of solar radiation at this

Figure 1.8


GLOBAL SOLAR RADIATION
(1985-1990 GROWING SEASONS)
GROUND SITE
VALUES FOR JULY 1987
WERE INTERPOLLATED
LANGLEYS/DAY
700
600
500
400
300
200
100
0
1985
1986
1987
1988
1989
1990
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
MONTH

site. Since the sensor is located above the canopy of the red pine plantation at all times, any statistically significant relationships between global radiation and ELF antenna operation would be coincidental. Given the current results of the ANOVA tests it does not appear that such a relationship exists and/or is detectable.

Table 1.10 Average global solar radiation during the 1985-1990 adjusted growing seasons.

Global Solar Radiation[1] (Langleys/Day)					
1985	**1986**	**1987**	**1988**	**1989**	**1990**
385.1 a[2]	360.9 a	364.0 a	331.0 a	383.2 a	363.5 a

[1]Averages and analysis using May-June, August-October. July was excluded from the analysis due to missing information from July 1987 and April 1988.
[2]Years with the same letter not significantly different at p=0.05

Relative Humidity

Atmospheric humidity is an influential factor determining rates of plant transpiration and respiration. Humidity is related to vapor pressure gradients which influence the amount of transpiration and evaporation from a given land area. In an attempt to fully monitor the climate at the study sites, relative humidity is measured by the ambient monitoring systems.

As a result of sensor repairs and system failures 1990 was the fourth year that relative humidity was monitored during the entire growing season. Calibration endpoints of the sensor at the ground site in 1990 drifted repeatedly making measurements collected at this site unusable. Thus annual comparisons and site comparisons are limited to 1987-1989 for the control vs. ground analysis. Initiation of relative humidity monitoring begins each year after snow melt. Generally there are only 14 to 21 days in April when relative humidity is monitored. In order to eliminate bias from comparisons of years or sites, April measurements were not included in the analyses.

Site Comparisons: During 1987-1990 relative humidity was higher at the test sites than at the control site (Table 1.11). Differences were significant ($p \leq 0.001$) for both the control vs antenna (1987-1990) and the control vs ground comparisons (1987-1989). Average relative humidity was 15.9% greater at the antenna than control site during 1987-1990 while relative humidity at the ground was 12.0% higher than at the control site during 1987-1989.

Annual Comparisons: Decreases in relative humidity from 1987 to 1989 appear to be related to decreases in precipitation. The increase in relative humidity in 1990 at the control and antenna site also appears to be related to the increase in precipitation above 1989 levels during this year. The ranking of average annual relative humidity during the growing season is as follows 1990>1987>1988>1989 and for the 1990>1987>1989 for the control vs. ground (Table 1.11).

Table 1.11 Comparison of relative humidity during the 1987- and 1990 (May-Oct.).

Relative Humidity (1987-1990)

	Ground	Antenna	Control	Control-Ground	Control-Antenna
1987	81.0	84.1	70.0	-11.0	-14.1
1988	80.0	80.0	62.5	-17.5	-17.5
1989	65.9	73.1	58.3	-7.6	-14.8
1990		87.3	70.3		-17.0
Mean (87-90)		80.9	65.3		-15.9
(87-89)	75.9		63.6	-12.0	

Relative Humidity %

Control	Ground
63.6 b	75.9 a
Control	**Antenna**
65.3 b	80.9 a

	1987	1988	1989	1990
Control vs Ground	75.5 a	71.2 b	62.1 c	
Control vs Antenna	77.1 b	71.2 c	65.7 d	78.8 a

[1/]Years with the same letter not significantly different at p=0.05

Site by Year Comparisons: Differences in relative humidity at the control and antenna sites range between 14.8 and 17.5%. Thus, site by year interactions were not significant for the control vs. antenna comparison (p=.771). However, site by year interactions for the control vs. ground comparison were significant (p=.045). This significant interaction appears to be related to the decreased differences among the two sites in 1989.

Summary: Site by year interactions were only significant for the control vs. ground comparison. Comparison of relative humidity during 1987-1989 at both the ground and control sites do not appear to show any specific trends related to the increase in EM fields by the ELF antenna.

Photosynthetically Active Radiation (PAR)

Photosynthetically active radiation is measured in the hardwood stands at the control an antenna sites. This climatic variable should be sensitive to possible ELF induced changes in the canopy of the hardwood stand. Reduction of foliage biomass or changes in the timing of leaf expansion would alter the amount of radiation reaching the forest floor over the duration of the growing season. This type of change would affect the growth of forest floor vegetation and the microclimate in the hardwood stands.

Sensor and system failures have limited the amount of months of data which can be used for this analysis. Currently measurements from May through July of 1986-1990 are used for ELF effect testing. Measurements during this time span should give a good indication of any changes in leaf area or timing of leaf expansion between the control and test sites.

Site and Annual Comparisons: Comparisons of sites and years are limited to the months of May through July of 1986-1990 due to the downtime of the platforms. Figure (1.9, 1.10) shows that PAR is dramatically reduced during May and June when leaf expansion of the hardwood stands occur. Thus the time period used in the analysis gives both an indication of the changes in the timing of leaf expansion as well as the total amount of light interception by the canopy over the five year period.

Average PAR was 1.29 Einsteins/day higher at the antenna site than at the control site during 1986-1990 (Table 1.12).

Figure 1.9

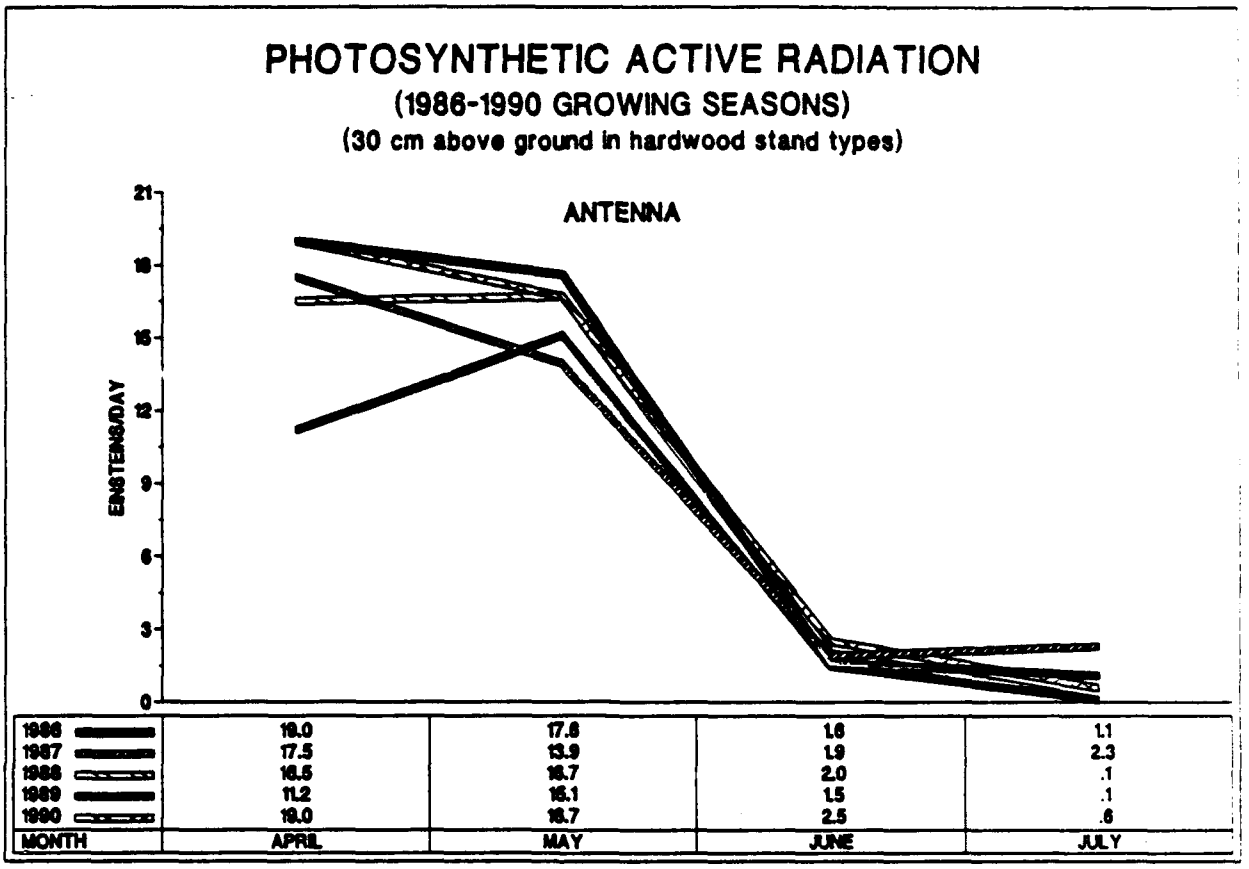


Figure 1.10

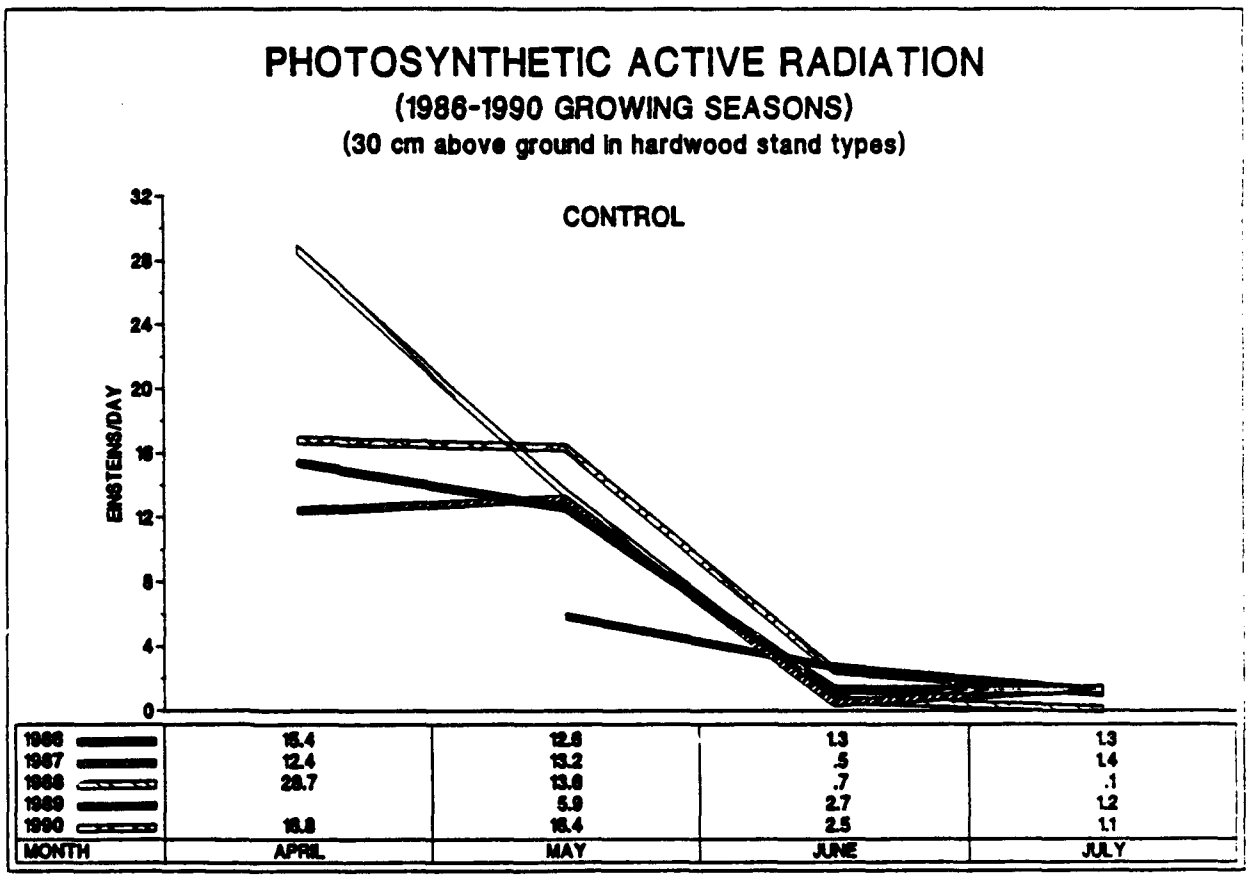


Table 1.12. Comparison of photosynthetically active radiation during 1986 -1990 (May-July).

	Average Daily PAR (Einsteins/Day)					
	1986	**1987**	**1988**	**1989**	**1990**	**x**
Control	4.77	5.06	4.53	3.27	6.42	4.81 a[1]
Antenna	6.33	5.83	6.10	5.56	6.69	6.10 a
Control-Antenna	-1.56	-0.77	-1.57	-2.29	-0.25	1.29
Average	5.55 a	5.45 a	5.31 a	4.42 a	6.55 a	5.47

[1] Sites and years with the same letter not significantly different at p=0.05

However, differences is PAR among sites were not significant (p=.207) for the current study period. Site by year interactions were also not significantly different (p=.510).

Summary: Detection limits for PAR are quite high because there is only one sensor at each site and the variability in PAR from year to year and from month to month is high. Thus it is not surprising that site, year, and/or site by year comparisons were not significant. Differences in PAR between the sites during the five year of measurements do not appear show any trends which are related to the ELF antenna operation.

Air Temperature (30 cm above ground)

Air temperature is being monitored 30 cm above the ground to give a more accurate measurements of climatic conditions at the understory air interface. These sensors were not operational in 1987 and thus analyses and summaries were only performed on the 1985-1986 and 1988-1990 measurements.

Site Comparisons: Average air temperature (30 cm) was 1.0 ^{o}C warmer at the control than at the antenna hardwood stand for the five years of measurements (Table 1.13). Differences in temperature (1.0 ^{o}C) between sites at 30 cm above the ground were similar in magnitude to site differences

in average air temperature at 2 m above the ground. However differences between sites were not significant (p=.064).

Annual Comparisons: Annual trends in air temperature (30) cm were similar to those found for air temperature 2 meters aboveground in the hardwoods at the two sites. The highest temperatures observed at 30cm aboveground were in 1988 and the lowest in 1985 and 1986. Average annual temperatures were not significantly different among years (p=.227) and site by year interactions were not significant (p=.943) for this years analysis.

Summary: The detection limits for this variable, like many other climatic variables which are only measured with one sensor at each site, are high (Table 1.15). Given the similarity in temperatures at aboveground heights of 2m and 30cm in the hardwood stands, it would appear that comparisons of air temperature at 2m would give a better indication of the effects of ELF antenna operation than would the 30cm temperature sensors. Regardless of the air temperature variable considered, there is no indication that ELF antenna operation has modified the air temperatures of this stand type.

Table 1.13 Comparison of air temperature 30 cm above the ground at the control and antenna hardwood stands during 1985, 1986, 1988, 1989, 1990

Average Daily Air Temperature 30 cm (^{o}C)

	1985	1986	1988	1989	1990	$\bar{X}$
Control	12.2	12.7	13.4	12.8	12.2	12.7 a[1]
Antenna	11.5	12.0	12.1	11.7	11.0	11.7 a
Control-Antenna	0.7	0.7	1.3	1.1	1.2	1.0
$\bar{X}$	11.8 a	12.4 a	12.8 a	12.3 a	11.6 a	12.2 a

[1] Sites and years with the same letter not significantly different at p=0.05

Detection Limits

Detection limits (DTL) calculated for the temperature variables (air, soil (5cm), and soil (10cm)) were generally lower than the DTL calculated for any of the other variables (Table 1.14, 1.15). The air temperature and soil temperature DTL are near the precision limits of the equipment and it is not expected that any improvement (decrease) of the DTL for these variables will be made in future analyses. Since the DTL are low for the temperature variables, it is also expected that these measurements will give the best indication of the effects of ELF radiation on the microclimate of the test sites. The higher DTL associated with moisture content and soil water potential measurements are in part a result of the lower precision of the soil moisture sensors as well as the high spatial variation of soil moisture within the sites.

Soil moisture content DTL were lower than soil water potential DTL for all depths (Table 1.14,1.15). DTL for site and year factors were below 15% of the mean for both soil moisture variables. DTL for site by year, site by stand type, and site by stand type by year interactions were also less than 15% for soil moisture content but not soil water potential.

DTL expressed as a percent of the overall study means for solar radiation and precipitation were often in excess of 30%. These high values are a result of only utilizing one sensor at a site. For these climatic measurements spatial variation is limited and one sensor is adequate for the accurate measurements of these variables. However, the lack of additional sensors reduce the sensitivity of the statistical tests employed in hypothesis testing.

DTL were also generally lower for the control vs. antenna comparisons than the control vs. ground comparisons (Table 1.14,1.15). The increased sensitivity of the control vs. antenna comparisons is a result of having two stand types (six plots) included in the analyses rather than just one stand type (three plots). The increased number of plots and thus observations for a given variable reduces the standard errors used in the calculation of the DTL associated with site, year, and site by year factors.

Summary

A large number of climatic factors were found to vary significantly among sites and/or years (Table 1.16-1.17). Air temperature (2m), soil moisture content at 5 cm and 10 cm depths, soil water potential at 5 cm, and relative humidity are climatic variables which have been found to differ among the control and tests sites. Air and soil temperature, soil moisture , soil water potential, precipitation, and relative humidity change annually at the sites. Any of these climatic variables which differ among sites and/or years are good candidates for modeling efforts or covariate analysis in the other elements of the project. However, before these climate

Table 1.14 Detection limits (DTL) and detection limits as a percent of overall mean (DTL%) for control vs ground site comparisons (1985-1990).

Variable	Site		Year		Site by Year	
	DTL[1]	DTL%	DTL	DTL%	DTL	DTL%
Air Temperature 2m (^{o}C)	0.6	4.7	0.3	2.2	0.4	3.1
Soil Temp. 5cm (^{o}C)	0.7	5.3	0.3	2.3	0.43	3.3
Soil Temp. 10cm (^{o}C)	0.5	3.6	0.3	2.2	0.4	3.1
Soil Moist. 5cm (^{o}C)	0.5	3.1	1.3	9.2	1.9	13.1
Soil Wat. Pot. 5cm (^{o}C)	0.20	11.4	0.37	21.3	0.52	30.0
Soil Moist. 10cm (^{o}C)	0.4	2.5	1.2	7.8	1.6	11.1
Soil Wat. Pot. 10cm (^{o}C)	0.26	14.1	0.37	21.5	0.53	30.4
Sol. Rad.(L d^{-1})			74.1	20.6		
Rel. Humidity (%).	1.5	2.2	1.2	1.7	1.7	2.4
Precip. (cm)	0.47	28.9	0.87	53.3	1.12	68.8

[1] DTL calculated at p=0.05

Table 1.15 Detection limits (DTL) and detection limits as a percent of overall mean (DTL%) for control vs antenna site comparisons (1985-1990).

Variable	Site		Year		Site by Year		Site by Stand Type		Site by Stand Type by Year	
	DTL[1]	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%	DTL	DTL%
Air Temp. (°C)	0.3	2.1	0.1	1.2	0.2	1.6	0.5	4.3	0.3	2.5
Soil Temp. 5cm (°C)	0.5	4.0	0.2	1.7	0.3	2.5	0.5	4.1	0.4	3.1
Soil Temp. 10cm (°C)	0.2	1.9	0.2	1.9	0.3	2.6	0.6	5.3	0.5	4.4
Soil Moist. 5cm (%)	1.0	7.9	0.7	5.6	1.0	7.8	1.4	11.4	1.4	11.2
Soil Wat. Pot. 5cm (-Mpa)	0.19	11.8	0.22	13.5	0.31	39.4	0.52	32.6	0.41	25.9
Soil Moist. 10cm (%)	1.6	13.0	0.7	5.6	1.0	7.9	2.0	16.6	1.7	14.0
Soil Wat. Pot. 10cm (-Mpa)	0.30	16.8	0.17	9.6	0.24	13.6	0.42	23.6	0.45	25.5
PAR 30cm (E/day)	3.51	62.1	1.73	30.5	0.84	14.8				
Relative. Humidity.	1.3	1.8	1.2	1.7	1.8	2.4				
Precip. (cm)	0.47	28.7	0.71	43.2	1.00	61.7				
A Temp. 30cm (°C)	1.2	9.4	1.4	11.4	1.0	8.2				

[1] DTL calculated at p=0.05

variables are included in any final analyses, it must be demonstrated that they are not correlated to and affected by the ELF antenna operation.

We expect that any change in a climatic variable as a result of ELF antenna operation would correspond to a change in the ecology at the test sites. To detect and quantify any changes in the climate at the test sites, comparisons of the climatic relationships between the control and test sites over the duration of the project are made. Changes in the relationships of the climate between the control and test sites would indicate possible ELF field effects on the ecology of the test sites. These changes are expressed in our statistical design through significant site by year and site by stand type by year interactions. As of the 1990 measurements air temperature (2m), soil moisture content (5cm) soil water potential (5cm), soil moisture content (10cm), and relative humidity were shown to have significant site by year interactions for the control vs ground comparisons and/or the control vs antenna comparison. During 1985-1990 no site by stand by year interactions were significant (Table 1.16-1.17).

Significant site by year air temperature (2 m) interactions have been shown to be related to the productivity of the red pine at the control and test sites. Thus at least for this climatic variable potential effects of ELF electromagnetic fields on air temperature cannot be addressed until the effects of these fields on the productivity of red pine have been quantified. As of the 1990 the significant interactions for soil moisture (5cm & 10cm) soil water potential (5cm), and relative humidity have not appeared to be related to ELF antenna operation or changes in vegetation productivity among the sites.

Another approach used to quantify the relationships between ELF antenna operation and ambient measurements is to determine the correlation coefficients between 76 hz field strengths and climatic variables. Significant correlations between these two factors would suggest that either ELF antenna operation has affected a given ambient variable or that an coincidental relationship exists between a specific climatic factor and antenna operation. Table 1.18 presents the results from this approach. Ambient measurements used for the correlations were plot or site averages, minimums, maximums, and/or totals for each year during 1985-1990, but only results from averages and totals are presented in Table 1.18. Magnetic field strengths were determined by integrating the field equations from EW leg operation while longitudinal fields were determined from isocline maps (Appendix A)

Soil moisture, solar radiation, precipitation, and relative humidity measurements (Table 1.18) were not significantly correlated with the magnetic for longitudinal fields. However, average daily air temperature was significantly correlated ($r=-.431$, $p<.001$) with longitudinal field strengths but not magnetic fields ($r=-.134$, $p=.208$). Average minimum daily air temperatures were more strongly correlated with both the longitudinal ($r=-.582$, $p<.001$) and

Table 1.16 Significant differences for control vs ground site comparisons (1985-1990)

	FACTOR		
Variable	Site	Year	Site by Year
Air Temp. (2m)	*[1]	*	*
Soil Temp. (5 cm)	-	*	-
Soil Temp. (10 cm)	-	*	-
Soil Moist. (5 cm)	*	*	-
Soil Wat. Pot. (5 cm)	-	*	-
Soil Moist. (10 cm)	*	*	*
Soil Wat. Pot. (10 cm)	-	*	-
Relative. Humidity.	*	*	*
Precipitation.	-	*	

[1] Factors denoted by * p<=.05.

Factors denoted by - p>.05

Table 1.17 Significant differences for the control vs antenna comparisons (1985-1990)

	FACTORS				
Variable	Site	Year	Site by Year	Site by Stand Type	Site by Stand Type by Year
Air Temp. (2m)	*[1]	*	-	-	-
Soil Temp.(5 cm)	-	*	-	-	-
Soil Temp.(10 cm)	-	*	-	-	-
Soil Moist.(5 cm)	*	*	*	*	-
Soil Wat. Pot.(5 cm)	*	*	*	-	-
Soil Moist.(10 cm)	*	*	-	*	-
Soil Wat. Pot..(10 cm)	-	*	-	-	-
PAR	-	-	-		
Air Temp.(30 cm)	-	-	-		
Rel. Hum.	*	*	-		
Precipitation	-	*			

[1] Factors denoted by * p<=.05

Factors denoted by - p>.05

Table 1.18. Correlation coefficients and significance levels (-.+,*, or **) associated with annual ambient variables and longitudinal, and magnetic EW leg antenna operation 76 hz field strengths (1985-1990).

	Longitudinal	Magnetic
Air Temperature 2 m	-.431 **	-.134 -
Soil Temperature 5 cm	-.113 -	-.202 +
Soil Moisture 5 cm	.070 -	-.153 -
Soil Temperature 10 cm	-.108 -	-.196 -
Soil Moisture 10 cm	-.045 -	-.156 -
Average Weekly Precipitation	-.171 -	-.157 -
Global Solar Radiation	.455 -	.282 -
Relative Humidity	.258 -	-.121 -
Solar Radiation Par	.417 -	.410 -
Air Temperature 30 cm	-.171 -	.236 -

1/ - .10<p
+ .10≥p>.05
* .05≥p>.01
** .01≥p

at depths of 5cm (r=-.202, p=.056) and 10cm (r-.196,p=.064) were significantly correlated with magnetic fields but not longitudinal fields ((5cm r=-.113, p=.287), (10cm r=-.108, p=.311)). Similar to air temperature average minimum daily soil temperatures were more strongly correlated to the fields than were average daily soil temperature. For example average minimum soil temperature (5cm) was significantly correlated to longitudinal fields (r=-.344, p<.001) and to magnetic fields (r=-.288, p=.006).

Plots of field strengths to air or soil temperature show a decreasing trend of temperature with increasing field intensity. Figures 1.11 and 1.12 show these trends for both the longitudinal and magnetic fields and temperature observations from all sites. Comparisons of longitudinal fields and average daily air temperature at the ground site (Figure 1.13) and the antenna site (1.14) only show the decreasing trends in air temperature with increasing field strengths. Although the correlations between the EM fields and temperatures are strong, they in now way indicate whether the temperature at the test sites have been altered by antenna operation. It is plausible that at least at this point in time, effects of temperate and EM fields may be confounded. Thus further monitoring of temperature and fields in the next few years of the project will be important for determining to what degree if any and in what ways temperature is related to the EM fields of the ELF antenna.

Soil Macronutrient Monitoring

Data Collection and Statistical Analysis

Soil nutrient samples have been collected monthly during the growing season since 1985. Soils are sampled using a push probe inserted to a depth of 15 cm in the mineral soil. Five composite samples made up of 4 randomly selected probes each are collected from each plot. These samples are dried at 60^{o}C, sieved and mixed, and analyzed for Kjeldahl N, total P, and exchangeable Ca, Mg, and K.

Analytical Results, Variability, and Detection Limits

Spatial variability of soil nutrients are high in temperate forest ecosystems. Thus variability of the nutrients in the study sites are also relatively high (Table 1.19). Variability of the Ca and Mg is greatest while variability of N is the least. Site detection limits range from 12.2% to 66.3% while detection limits for year factors are lower with a range of 6.0% to 17.8%. The increased detection limits associated with the site compared to the year factor is directly attributed to the large spatial variability associated with soil elemental concentrations. The low detection limits associated with the annual measurements of soil nutrients are well within the accuracy needed for use as a covariate or modeling variable associated with temporal changes in other study elements.

Figure 1.11 LONGITUDINAL 76 Hz FIELD ALL SITES vs. AIR TEMPERATURE

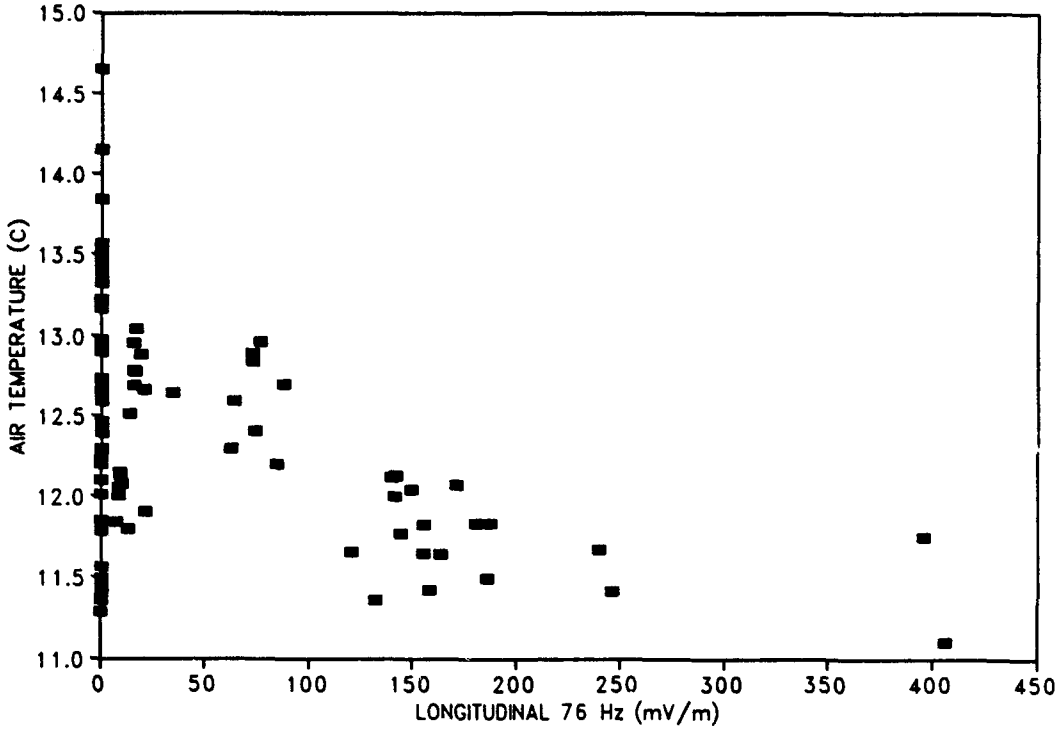


Figure 1.12 MAGNETIC 76hz FIELDS ALL SITES vs. AVERAGE MINIMUM SOIL TEMP. 5 cm

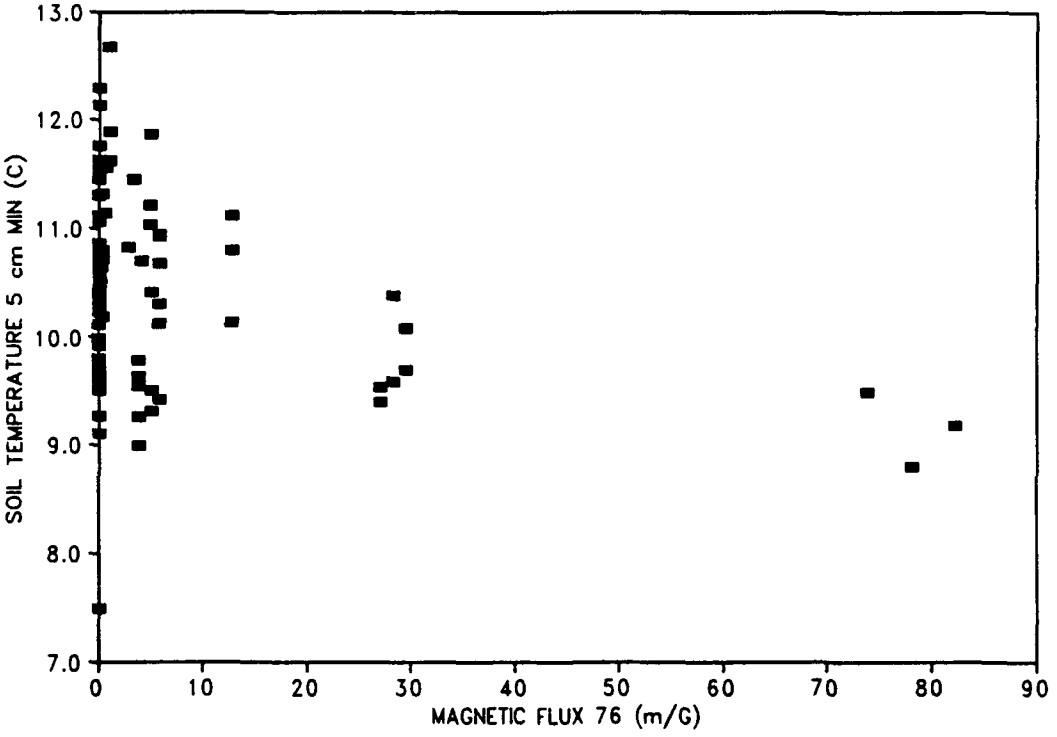


Figure 1.13

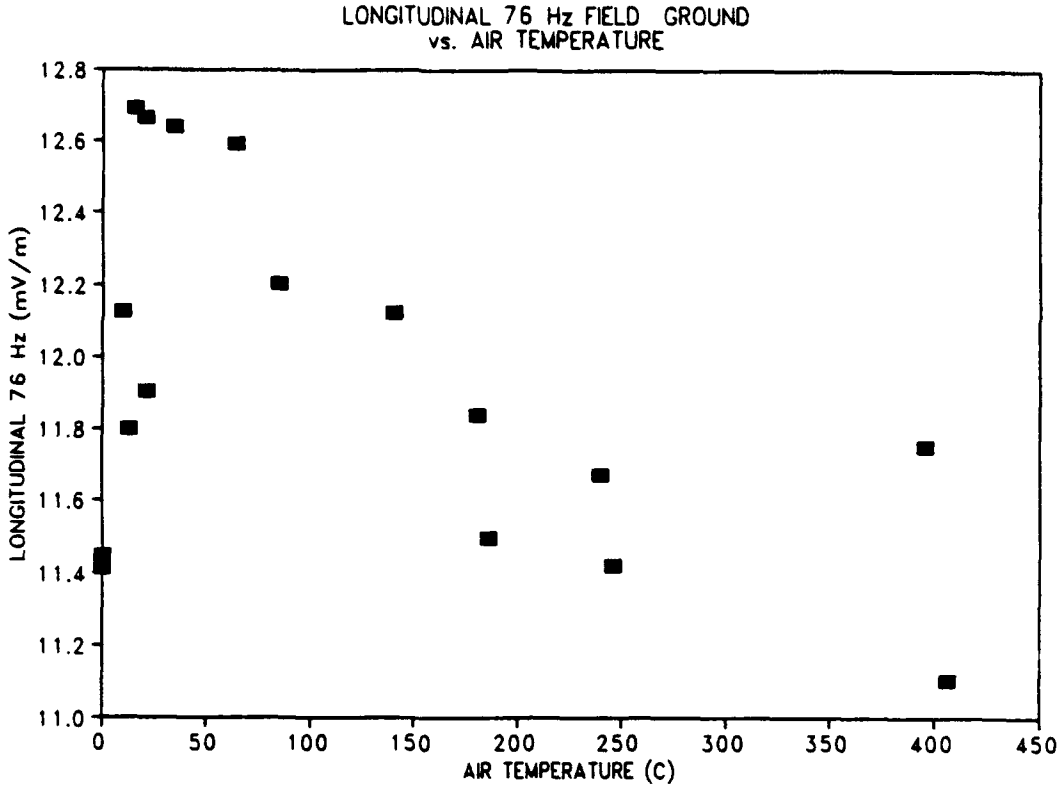


Figure 1.14

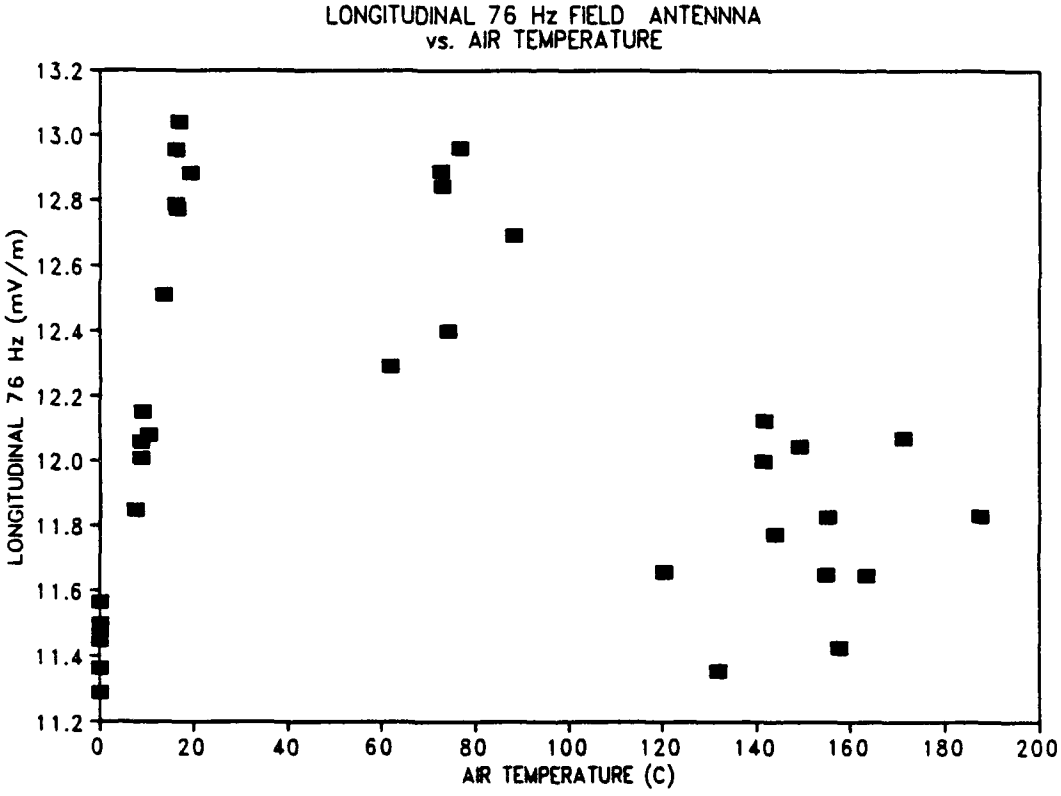


Table 1.19 Summary of measured soil nutrient variables.

Variable	Coefficient of Variation[a/] (%)	Detection Limit (%)[b/] Sites	Years	Pre-operational Years[c/]	Post-operational Years[c/]
Soil Nutrient-Hardwood					
Ca	56.5	66.3	14.1	1986-1989	1990-1993
Mg	42.2	39.4	9.6		
K	29.9	22.5	8.1		
N	24.0	12.2	6.0		
P	33.6	15.6	13.7		
Soil Nutrient-Plantation					
Ca	48.0	35.3	16.8	1986-1989	1990-1993
Mg	39.5	34.0	8.8		
K	38.2	25.5	9.5		
N	30.3	24.8	7.4		
P	39.5	34.7	17.8		

a/ Coefficient of Variation = (Standard Deviation/Mean)*(100), value given is for most recent measured year.
b/ Percentage change in the variable for which there is a 50 percent chance of detection at p=0.05.
c/ Pre-operational years are defined as years prior to full power (150 amp) antenna operation in 1990, post-operational years are 1990 and after, including proposed work in FY92, 93, and 94.

Analyses indicated that only Ca in the plantations was significantly different ($p \leq 0.05$) between the control and test sites during the 1986-1989 study period. To a large degree the lack of differences among the sites may be due to the high spatial variability in soil nutrients at the sites. A number of elements (Ca, Mg, and N) in both the hardwood and plantations were found to vary significantly among years. Detection of these changes is partially related to the lower detection limits associated with the annual time factors. However, annual changes in nutrient contents of Ca and N were often much larger than are expected in temperate forest ecosystems. While annual differences were found for a number of the nutrients, there were no significant site by year interactions for any element in either the hardwoods or plantations (Table 1.20). This indicates that even though the nutrient values may fluctuate annually, the relationship among the sites have remained constant over the study period and that at the given detection limits no change in site nutrients due to ELF have been found. Reviewers in the past have suggested that the high variability in the nutritional values may be a result of poor quality control in laboratory analysis. Considering the detection limits associated with site and year factors and the stable relationship of elemental contents among sites over four year study period, it appears that the variability in nutrient values for a given year are due to spatial variability within the study sites whereas the differences of elemental contents among years are related to laboratory soil analytical quality control.

Summary of Results and Direction

There has been no indication that the ELF antenna operation has affected the macronutrient concentrations at the test sites. Efforts in past years with nutrient monitoring has indicated a large spatial and temporal variability of soil nutrients. Although this variability reduces the value of soil nutrients as an ELF response variable, nutrient information has been an important component of ANCOVA and modeling efforts in a number of elements. Given the importance of soil nutrient information to the project as a whole soil nutrient monitoring is continuing with a revised sampling procedure. In 1992 and 1993 soil sampling will be done in only June and July. These months have been found to make the greatest contribution to the other study elements. Soil samples from these two months will be composited for analysis to reduce spatial and temporal variability. In response to the comments of reviewers and the excessive changes in soil nutrient contents in previous years, soils archived from June and July from 1986 to the present have also been composited. These samples are being analyzed using new laboratory quality control procedures. Additionally ANCOVA will be used to attempt to reduce spatial and temporal variability. An interim comparison of soil data will be included in the FY-92 annual report to with final summarization and analysis of soil nutrients to be completed in 1994.

Table 1.20. Summary of statistical analyses and results for soil nutrient variables.

Variable	Test Procedure[a/]	Covariates (If Appropriate)	Findings Through 1990[b/]
Soil Nutrient			
Ca	ANOVA		No detectable effect
Mg			No detectable effect
K			No detectable effect
N			No detectable effect
P			No detectable effect

a/ ANOVA = Analysis of Variance
b/ All statistical tests are at p=0.05.

Soil Nitrogen Mineralization

Tree productivity analysis completed during the past years have indicated that soil nutrients are valuable covariates in explaining site and year differences. Of these nutrients, nitrogen (N) is the one required by trees in the greatest quantity (Auchmoody and Filip 1973; Stone 1973; Keeney 1980). Trees assimilate N almost entirely in the inorganic state as either NH_4^+ or NO_3^- (Miller and Donahue 1990). However, the bulk of the nitrogenous materials found in soils or added to them as plant litter is organic, and consequently, the rate at which organic N is converted to NH_4^+ and further oxidized to NO_3^+ is critically important. However, past study efforts have only investigated total N levels in the soil. In response to reviewer comments we initiated a study in 1990 which will investigate the effects of N availability on tree growth. The study uses the buried bag technique described below to estimate N mineralization rates. When used with other growth regulating covariates, mineralization rate should help to refine our understanding and modelling of growth. Naturally, mineralization rates will also have to tested to show independence of ELF effects.

During this past year, efforts have focused on gathering field data and analyzing for site, stand and temporal effects. The comparisons in this report constitute major progress in this stage of study. Once completed, the data will be included in growth modelling efforts. If mineralization proves to be a valuable addition to these models, work will proceed to develop a model which predicts mineralizable N from our past measures of total N and climate related variables.

Background

The conversion of organically bound N to inorganic N (mineralization) describes two distinct processes: ammonification, in which NH_4^+ is formed from organic compounds; and nitrification, the oxidation of NH_4^+ to NO_3^- (Carlyte 1986). Forest floor and surface mineral soils are two important sites for N mineralization, since most substrates and microorganisms that mediate N mineralization have been found in these two horizons. The objective of this study is to estimate rates of ammonification and nitrification in both red pine plantations and hardwood stands at the antenna and control sites. The overall hypothesis for this study is

Ho: There are no differences in the rates of N mineralization (ammonification and nitrification) rates in both forest floor and mineral soil (0-10 cm) between antenna and control sites.

Sampling and Data Collection

This study was conducted at antenna and control sites. Nitrogen mineralization (ammonification and nitrification) were measured in three replicate hardwood plots and three red pine plantation plots at each site, respectively. An *in situ* buried bag technique was used to determine net ammonification and nitrification in forest floor and mineral soils (0-10 cm).

Soil Incubation

Soil sampling points were randomly selected within plots at each site. Samples were taken of both forest floor and mineral soils by using a soil core 5 cm in diameter and 15 cm in depth. The thickness of the forest floor at each sampling point was measured before sample collection. Based on the thickness of the forest floor, a soil core was collected to obtain a mineral soil sample of 10 cm depth. Core samples were removed from the hole and placed undisturbed into a polyethylene bag (0.001 mm thick), tied, returned to the same hole, covered with the litter, and then incubated for four weeks. A separate forest floor sample was collected (about 100 g) near the core sampling point to determine moisture content. A second core sample of both forest floor and mineral soil was collected next to each soil incubation core to determine initial soil NH_4^+ and NO_3^- levels, and bulk density.

Laboratory Procedures

All samples sent to the soil laboratory were stored at 2^0C. The forest floor in each core sample was separated from mineral soil as described by Federer (1982). Five grams of forest floor were extracted with 2 M KCL (Bremner 1965) and the extracts analyzed for NH_4^+ and NO_3^- using an automated spectrophotometer (Technicon 1978). Forest floor samples taken to determine moisture content were dried at 105^0C for 48 hours. Mineral core samples were homogenized and 5 grams were taken and extracted with 2 M KCL and analyzed for NH_4^+ and NO_3^-.

Net ammonification rate during the incubation period was determined by subtracting the initial soil NH_4^+ content from the NH_4^+ content after 4 week incubation. Likewise, net nitrification rate during the incubation was determined by subtracting initial soil NO_3^- value from the NO_3^- content of the incubation sample. Net N mineralization rates were obtained by summing the ammonification and nitrification rates during the incubation period. Soil pH, moisture

content and bulk density were measured on all samples. Forest floor and mineral soil (0-10 cm) pH was measured potentiometrically with a glass microelectrode using a 1:5 fresh forest floor:deionized water ratio and a 1:1 fresh soil:deionized water ratio. Subsamples were taken and dried at 105°C for 48 hours to determine soil moisture content. Air dried subsamples were sieved through a 2 mm screen to quantify coarse fragment (>2 mm), and the <2 mm sample fractions of the initial and incubated samples at same sampling point were composited. Soil organic carbon, and total N were measured on the composited samples.

Data Analysis

Statistical analysis was conducted on one complete year (from May 1990 to April 1991) of sample collection. A split-plot design was used to determine the site and month differences in net ammonification and nitrification rates between antenna and control sites (Table 1.21). Significant differences between sites and among months indicated by the ANOVA tests were separated with Student-Newman-Keuls (SNK) procedure. Detection limits for ammonification and nitrification were calculated using the Student-Newman-Keuls (SNK) multiple range test. Person's correlation coefficient was used to determine linear relationships among ammonification, nitrification and major soil properties (moisture, temperature, organic carbon, organic matter, bulk density, and pH). All tests were performed with a p=0.05 probability level.

Progress

Soil incubation started on April 30, 1990. Forest floor and surface mineral soil (0-10 cm) samples were incubated at four week intervals during the growing season (from May to September 1990). Samples were incubated over winter (from October 1990 to April 1991). The total amounts of ammonification and nitrification were divided by the numbers of four week intervals during these winter months to express results as monthly means. Bulk density measures were used to convert rates of ammonification and nitrification in concentrations to a weight per unit area basis (kg ha^{-1} yr^{-1}).

Ammonification in the Forest Floor

Site comparisons: Mean annual rates of ammonification in both stand types were lower at the antenna than those at the control site (Table 1.22). Results of the ANOVA tests indicated that the rates of ammonification were significantly different at the site level (p=0.02, Table

Table 1.21. Analysis of variance for the net rates of ammonification and nitrification in both forest floor and mineral soil (0-10 cm) between Control and Antenna sites.

Source of variance	df	Sum of Squares	Mean Squares	F - Ratio
Site	1	SS_S	MS_S	$MS_S/MS_{P(S)}$
Plot(site)	4	$SS_{P(S)}$	$MS_{P(S)}$	
Stand type	1	SS_T	MS_T	$MS_T/MS_{TP(S)}$
Stand type * Site	1	SS_{TS}	MS_{TS}	$MS_{TS}/MS_{TP(S)}$
Stand type * Plot(site)	4	$SS_{TP(S)}$	$MS_{TP(S)}$	
Month	5	SS_M	MS_M	$MS_M/MS_{MP(S)}$
Month * Site	5	SS_{MS}	MS_{MS}	$MS_{MS}/MS_{MP(S)}$
Month * Plot(site)	20	$SS_{MP(S)}$	$MS_{MP(S)}$	
Stand type * Month	5	SS_{SM}	MS_{SM}	$MS_{SM}/MS_{MTP(S)}$
Site * Stand type * Month	5	SS_{STM}	MS_{STM}	$MS_{STM}/MS_{MTP(S)}$
Month * Stand type * Plot(site)	20	$SS_{MTP(S)}$	$MS_{MTP(S)}$	

Table 1.22. Comparison average rates of ammonification and nitrification (kg N ha^{-1} yr^{-1}) in forest floor from May 1990 to April 1991

	Site Comparison			
	Plantation		Hardwood	
	AMMON	NITR	AMMON	NITR
Antenna	0.03a	0.22	-0.21a	0.08
Control	0.44b	0.21	0.92b	0.02

	Monthly Comparison			
	Plantation		Hardwood	
	Antenna	Control	Antenna	Control
	Ammonification			
May	-0.75*a*	-0.04	-2.62*a*	-0.82*a*
June	-0.55*a*	0.60	-1.45*a*	0.64*a*
July	0.15*a*	0.91	0.38*b*	0.41*a*
August	1.75*b*	0.46	0.32*b*	0.63*a*
September	-0.29*a*	0.88	0.93*b*	4.55*b*
Oct-Apr	-0.23*a*	-0.19	-0.13*b*	-0.20*a*
	Nitrification			
May	0.01	0.04	-0.13	-0.002
June	-0.24	0.10	0.03	-0.004
July	0.36	0.49	0.24	-0.02
August	0.76	0.40	0.15	0.05
September	0.55	0.22	0.04	0.24
Oct-Apr	-0.16	-0.07	-0.002	-0.16

Note: (1) AMMON = Ammonification; NITR = Nitrification.
(2) Values in a column followed by different letters are significantly different at $p<0.05$.

1.23). However, stand type and site by stand type interaction for ammonification rates did not show significant differences at p=0.05 (Table 1.23). These results indicate that differences in the rates of ammonification in forest floor between the hardwood and red pine plantation stands are similar at the both sites.

Monthly comparisons: Rates of ammonification in forest floor show a clear seasonal trend through the year (Figure 1.15*a* and 1.15*b*). The ammonification rates in the hardwood stands were least in May and the highest in September for both antenna and control sites. Although the seasonal trends at the hardwood stands were similar at the both sites, the monthly minimum rate at the control site was about three times less than that at the antenna, while the highest rate at the control was approximately five times more than that of the antenna site. Rates of ammonification in the red pine plantations had similar seasonal trends through the year but the variations were smaller than those in the hardwood stands (Figure1.15*b*)

Differences in the rates of ammonification in the hardwood stand were significant among months at both the antenna and control sites (p<0.001). Site by month and stand type by month interactions showed significant differences (Table 1.23). Multiple range tests indicate that rates of ammonification in the antenna site were similar between May and June, or among July, August, September, and the winter months (October to April), but significantly different in May and June vs the other months (Table 1.22). At the control site, rates of ammonification were not significantly different through the year except in September. Similar results were found for rates of ammonification at the antenna plantations where the highest rate was found in August. This was significantly different than the other months. However, the monthly rates of ammonification in the plantation stand at the control were not any significant difference through the year (Table 1.22).

Nitrification in the Forest floor

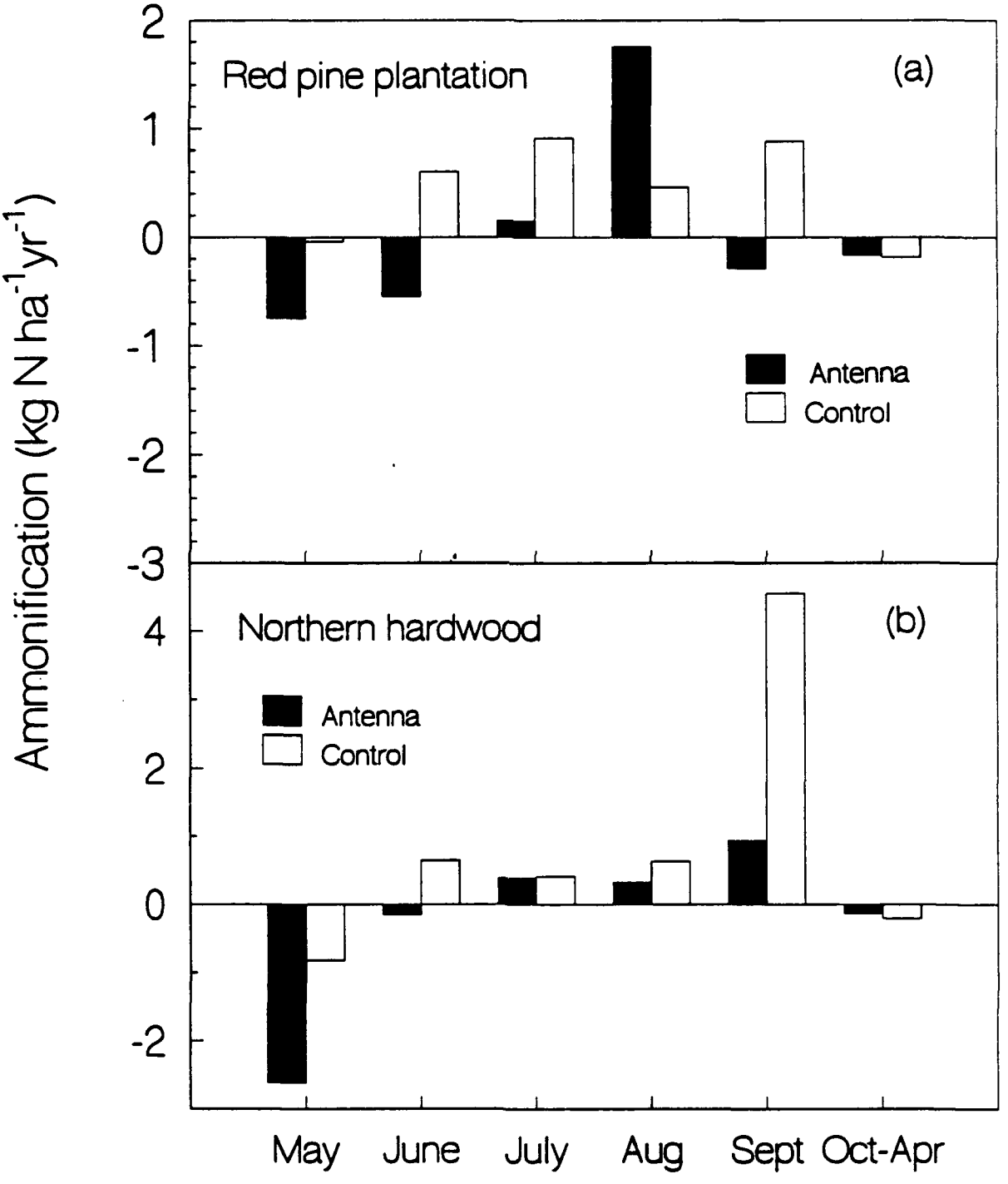
Site comparisons: Mean annual rates of nitrification were similar between antenna and control sites (Table 1.22) and no significant differences were detected in the ANOVA test (p=0.791, Table 1.23). Stand type and site by stand type interactions were also not significantly different (p=0.721). These tables show that differences in the rates of nitrification in forest floor at both the hardwood and the red pine plantation stands are similar at the two sites.

Monthly comparisons: Rates of nitrification in forest floor show a clear seasonal trend through the year (Figure 1.16*a* and 1.16*b*). The nitrification rates in the red pine

Table 1.23. Significant levels from the analysis of variance for ammonification and nitrification (kg N ha^{-1} yr^{-1}) in forest floor and Detection limits (p=0.05) associated with site, stand type, and stand type by site interaction

Factor	Ammonification	Nitrification
Site	0.020	0.791
Month	0.000	0.197
Month * site	0.002	0.972
Stand type	0.748	0.816
Stand type * site	0.348	0.721
Stand type * month	0.033	0.431
Stand type * month * site	0.600	0.544
	Detection Limits	**Detection Limits**
Site	0.731	0.280
Stand type	0.047	0.247
Stand type * site	0.284	0.352
	% Mean	**% Mean**
Site	121.1	48.1
Stand type	82.6	54.5
Stand type * site	58.0	38.2

Figure 1.15. Monthly average net ammonification in forest floor



plantation stands were lowest in the winter months (October to April) and the highest in July and August. Rates of nitrification in the hardwood stand had a similar seasonal trend at the antenna through the year but the seasonal trend in the control site was not as clear as that at the antenna site (Figure 1.16*b*). For example, the rates of nitrification at the control were close to zero during May and June, became negative in July, then increased to the highest level in September.

No significant differences were found for monthly comparisons (Table 1.23). Site by month, stand type by month, and stand type by site by month interactions were also not significant. Thus it appears that the seasonal trend in nitrification rates in the forest floor at antenna and control sites are similar over the year.

Foster (1989) reported similar seasonal trends for nitrification and total N mineralized in a maple-birch forest floor in central Ontario. Nitrogen mineralization was particularly sensitive to changes in average daily temperatures (Foster 1989). In our study, the average monthly temperatures at 5 cm depths were also significantly correlated with the ammonification (r=0.88, p=0.020) and nitrification (r=0.82, p=0.048) at the control site. At the antenna site, ammonification and nitrification in the pine plantation was significantly correlated with moisture content (r=0.80, p=0.057; r=0.96, p=0.003, respectively). However, the ammonification and nitrification in either of the hardwood stand were not significantly correlated with average monthly temperature and moisture contents.

Ammonification in the Mineral Soil (0-10 cm)

Site comparisons: Mean annual rates of ammonification at the antenna and control sites were smaller in the red pine plantation than in the hardwood stands (Table 1.24). Results of the ANOVA test indicate that the rates of ammonification were significantly different between the stand types (p=0.047). However, site and site by stand type interaction for ammonification rates did not show significant differences (Table 1.25). These results indicate that differences in the rates of ammonification in mineral soil (0-10 cm) between the hardwood stands and red pine plantations were similar for both sites.

Monthly comparisons: Rates of ammonification in the red pine plantation showed a clear seasonal trend (Figure 1.17a). The ammonification rates were minimal in May at the antenna site and during the winter months at the control site. From May to July, ammonification at both sites increased and reached a seasonal peak in July. Similar seasonal trends in ammonification were observed in the

hardwood stands at the both sites (Figure 1.17b) except maximum rates were evident in June rather than in July. During the winter months (from October 1990 to April 1991), the rates of ammonification and immobilization seem to be balanced at both sites giving a net ammonification close to zero (Figure 1.17b).

Differences in the rates of ammonification for both the red pine plantations and hardwood stands were significantly different among months ($p<0.001$). Site by month and stand type by month interactions were also significant (Table 1.25). Multiple range tests indicated that rates of ammonification at the antenna site were significantly higher only in July (Table 1.24). Similar results were found for ammonification rates at the control hardwood stand. The highest rate was found in June and was significantly different than the other months.

Nitrification in the Mineral Soil (0-10 cm)

Site comparisons: Mean annual rates of nitrification in were similar at antenna and control sites (Table 1.24) and differences between sites were not significant ($p=0.114$, Table 1.25). Stand type and site by stand type interactions for nitrification rates were also not significantly different ($p=0.278$, and 0.875, respectively). Thus differences in the rates of nitrification in mineral soils at both the hardwood and red pine plantation were similar at the two sites.

Monthly comparisons: Rates of nitrification at the red pine plantations show distinct seasonal trends through the year (Figure 1.18a). The ammonification rates at the sites generally increased from May to July and decreased to the minimum during the winter months. However, rates of nitrification in the hardwood stands did not show clear seasonal trends (Figure 1.18*b*). The rates at the antenna site was at a minimum in May and increased slowly in June. In July, rates increased to the seasonal peak and rapidly decreased in August. The net nitrification rates were near zero during September and the winter months. In the control site, nitrification was slow from May to July. The seasonal peak was found in August, then decreased through the rest of the year.

Nitrification rates in the red pine plantations were significantly different among months ($p<0.001$). Site by month interaction also showed significant differences ($p<0.001$) but stand type, stand type by site, stand type by month, and stand type by site by month interactions did not show significant differences (Table 1.25). Multiple range tests indicated that nitrification rates at the plantations were significantly higher in July (Table 1.24). At the

Figure 1.16 Monthly average net nitrification in forest floor

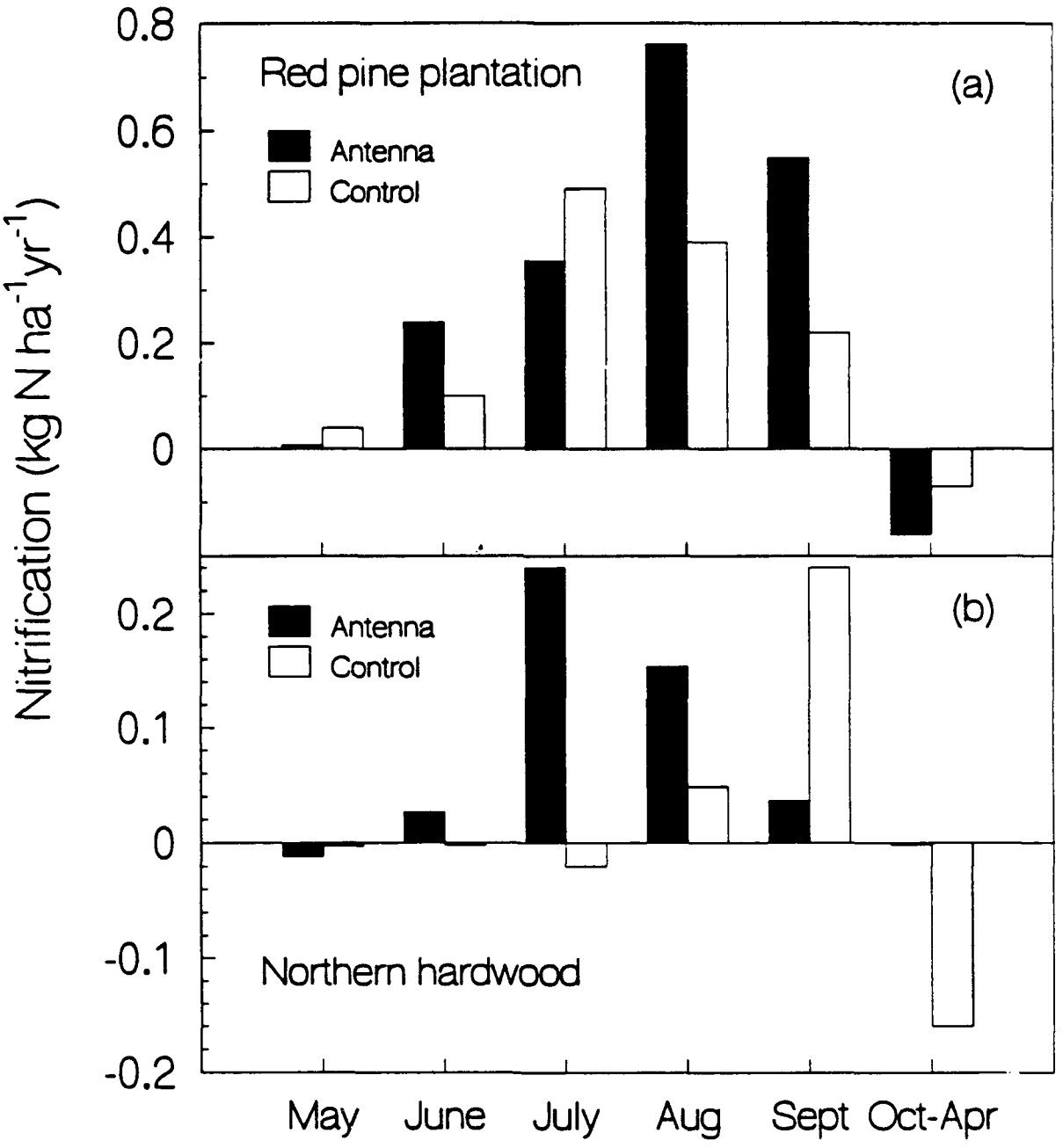


Table 1.24. Comparison average rates of ammonification and nitrification (kg N ha^{-1} yr^{-1}) in mineral soil (0-10 cm) from May 1990 to April 1991

	Site Comparison			
	Plantation		Hardwood	
	AMMON	NITR	AMMON	NITR
Antenna	1.77	0.88	2.04	0.46
Control	1.26	0.49	2.63	0.16

	Monthly Comparison			
	Plantation		Hardwood	
	Antenna	Control	Antenna	Control
May	-0.69*a*	0.97*ab*	-0.17*a*	-0.03*a*
June	0.47*a*	4.03*b*	5.01*b*	8.22*b*
July	7.01*b*	1.94*ab*	3.13*ab*	2.42*a*
August	0.98*a*	0.61*ab*	3.41*ab*	2.49*a*
September	1.28*a*	0.32*ab*	0.79*a*	2.75*a*
Oct-Apr	-0.05*a*	-0.32*a*	0.07*a*	-0.05*a*
	Nitrification			
May	0.13*a*	0.50*a*	-0.02	-0.04
June	0.86*a*	1.08*b*	0.11	0.03
July	2.71*b*	0.25*a*	2.58	0.02
August	0.91*a*	0.50*a*	0.25	0.73
September	0.61*a*	0.31*a*	-0.0004	0.18
Oct-Apr	0.07*a*	0.12*a*	0.002	0.04

Note: (1) AMMON = Ammonification; NITR = Nitrification.
(2) Values in a column followed by different letters are significantly different at $p<0.05$.

Table 1.25. Significant levels from the analysis of variance for ammonification and nitrification (kg N ha^{-1} yr^{-1}) in mineral soils (0-10 cm) and Detection limits (p=0.05) associated with site, stand type, and stand type by site interaction

Factor	Ammonification	Nitrification
Site	0.731	0.114
Month	0.000	0.000
Month * site	0.007	0.000
Stand type	0.047	0.278
Stand type * site	0.284	0.875
Stand type * month	0.005	0.831
Stand type * month * site	0.262	0.912
	Detection Limits	**Detection Limits**
Site	1.345	0.520
Stand type	0.946	0.778
Stand type * site	1.347	1.108
	% Mean	**% Mean**
Site	138.1	95.6
Stand type	196.5	63.9
Stand type * site	137.9	44.9

Figure 1.17 Monthly average net ammonification in mineral soils (0-10 cm)

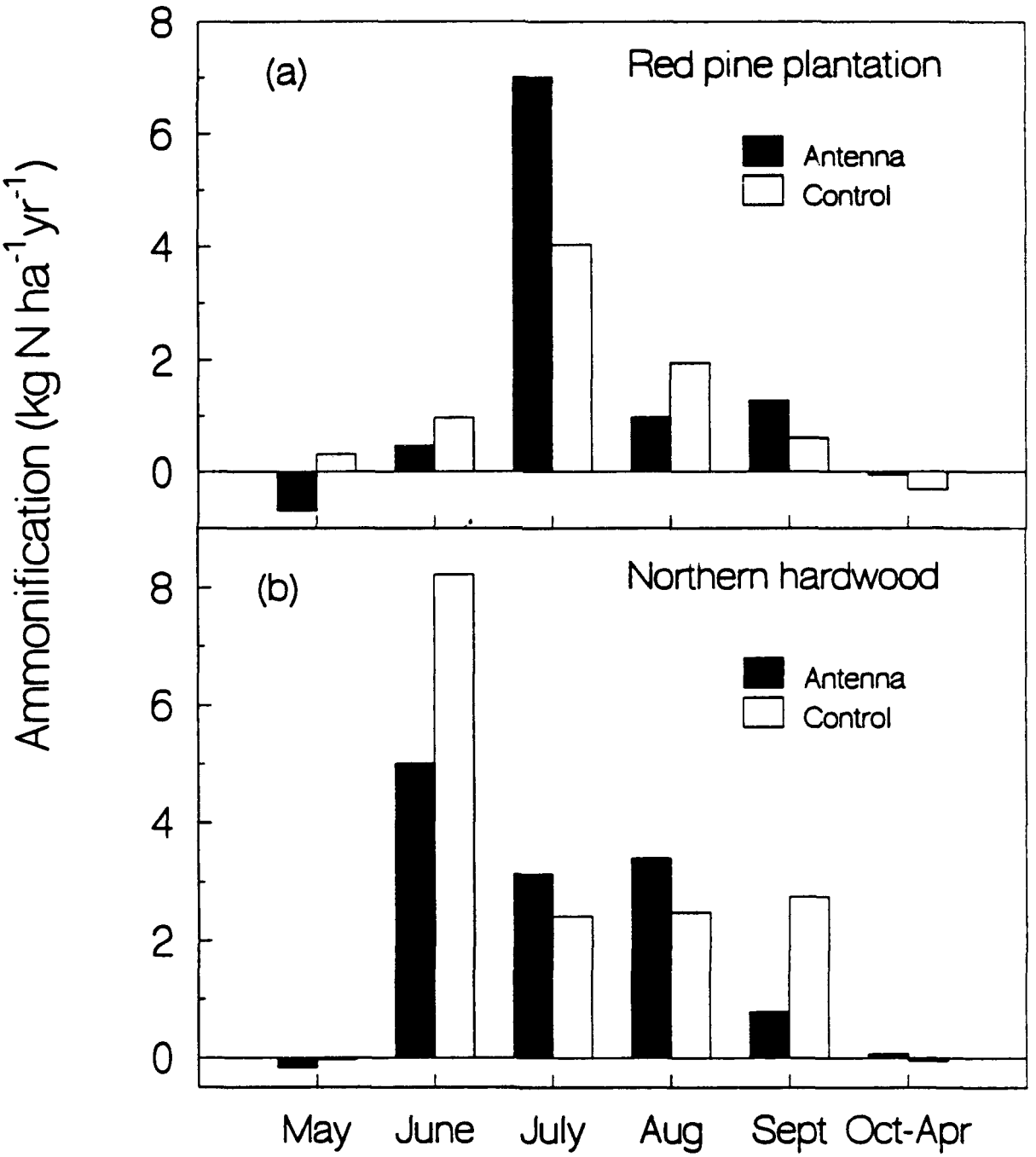
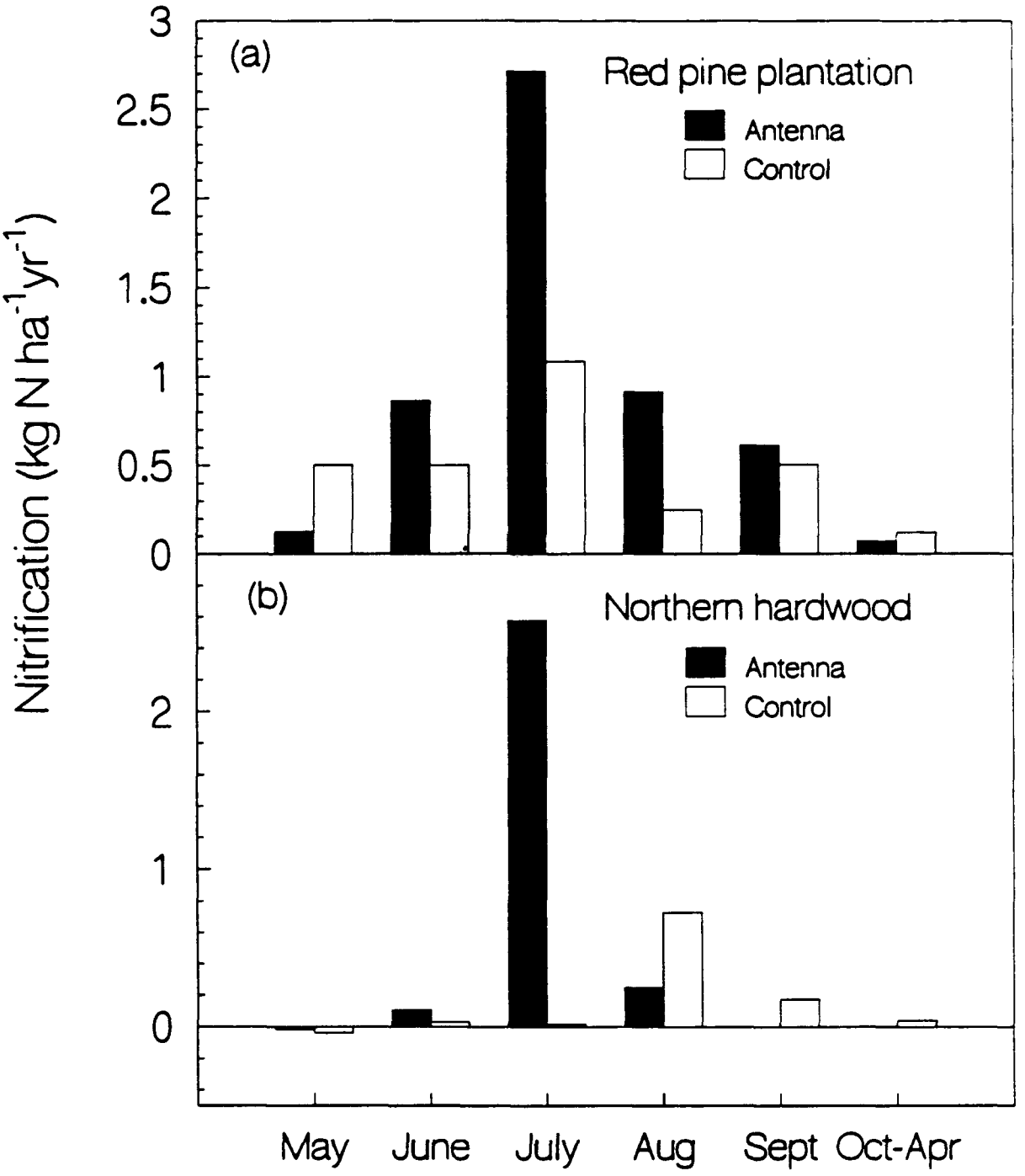


Figure 1.18 Monthly average net nitrification in mineral soils (0-10 cm)



control site, rates of nitrification were significantly higher in June than the others. Monthly rates of nitrification in the hardwood stands were not significantly different at either site (Table 1.24).

Mladenoff (1987) found similar seasonal trends for soil N mineralization and nitrification in hemlock and hardwood stands of southern Wisconsin. Climate and soil factors would seem to be the controlling factors for these seasonal variations of N mineralization and nitrification. Comparing the ammonification and nitrification rates in our study with soil temperature at 10 cm depth, moisture content (10 cm), bulk density, organic carbon, organic matter content, and pH, the ammonification rates were found significantly correlated with bulk density (r=0.44, p=0.033), and moisture content (r=0.32, p=0.001) but not the other factors. The nitrification rates were significantly correlated with bulk density (r=-0.21, p=0.014), and pH (r=-0.18, p=0.039).

Summary

Annual rates of forest floor ammonification were found to be significantly different between sites (p=0.020). However, rates of nitrification in forest floor or ammonification and nitrification in mineral soil were not found to be significantly different. Although ammonification rates in mineral soil (0-10 cm) were significantly different between the plantation and hardwood stands (p=0.047), stand type by site interaction was not significant (p=0.284).

Clear seasonal trends of ammonification and nitrification rates in forest floor and mineral soils (0-10 cm) were observed through the year. Differences in climate and soil properties through the year are the probably contributors to seasonal variations of both ammonification and nitrification. Average monthly temperatures at the 5 cm depth were significantly correlated with ammonification (r=0.88, p=0.020) and nitrification (r=0.82, p=0.048) at the control site. At the antenna site, ammonification and nitrification in the red pine plantations were significantly correlated with moisture content (r=0.80, p=0.057; r=0.98, p=0.003, respectively). However, the ammonification and nitrification in the hardwood stands were not significantly correlated with either the average monthly temperature at 5 cm depth or moisture content. In mineral soils (0-10 cm), the ammonification rates were significantly correlated with bulk density (r=-0.44, p=0.033), and moisture content at the 10 cm depth (r=0.32, p=0.001). The nitrification rates were significantly correlated with bulk density (r=-0.21, p=0.014), and pH (r=-0.18, p=0.039).

Detection limits of both ammonification and nitrification rates associated with the analysis of variance were generally high (Table 1.23 and 1.25). For example, the detection limit of ammonification rates in the forest floor was 121.1 % possibly because N mineralization is a microbial process which is influenced by the differences of climate and soil factors between the two sites. When these influential factors are introduced as covariates in the analyses, these high detection limits are expected to decrease.

Our results had low N mineralization in both hardwood (18-20 N kg ha^{-1} yr^{-1}) and plantation (14-16 N kg ha^{-1} yr^{-1}) Compared to similar studies, Nadelhoffer and Aber (1983) reported that N mineralization in sugar maple standsof southern Wisconsin was 62.1 kg ha^{-1} yr^{-1} and 32.4 kg ha^{-1} yr^{-1} in red pine plantations. Although this ccmparison is only for one years' results, there are several possible causes for such differences including:

1) differences in soil factors (temperature, moisture, pH, and C:N ratio)

2) differences in stand history (disturbance in logging)

3) differences in litter quality controlling N mineralization rates. These include the nature of the carbon and nutrient sources, surface toughness, particle size and moisture uptake (Carlyle 1986). Litter quality varies between and within species, depending on site conditions (Berg and Ekbohm 1983) and age (McGill etal. 1981.).

4) differences in methods used to measure N mineralization. Generally, methods used to determin soil N mineralization under field conditions are: (i) burying disturbed soil in plastic bags (Eno 1960); (ii) burying undisturbed columns in plastic bags (Matson and Boone 1984); (iii) burying ion exchange resins in the soil (Binkley and Matson 1983); (iv) modeling approach (Macduff and White 1985). So far, no one method is sufficiently reliable to measure N mineralization accurately under all field conditions. Some researchers using *in situ* buried bag techniques to measure N mineralization in forest floor and mineral soil separated these layers prior to incubation. This approach can overestimate N mineralization because of disturbance before incubation. In this study, the method kept the forest floor and mineral soil core intact and separated them after incubation in an attempt to minimize this effect. However a possible limitation of this method is movement of mineral N between horizons within the bags, which can result in re immobilization of mineralized N.

Element 2. Tree Productivity

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to treatment, accurate tree measurements are essential. The most widely accepted tree growth measurements are diameter at breast height outside bark (dbh) and height. Of these two growth variables, height is the more difficult to measure on mature trees. The installation of permanent dendrometer bands on the stem of a tree allows measurement of minute changes (0.008 cm) in diameter over a short time interval (Husch *et al.* 1982). Two additional advantages of using dbh as a measure of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1986) and the strong correlation between dbh and total tree biomass (Crow 1978). Consequently, measurement of diameter increment is the primary response variable for assessing the effects of ELF fields on hardwood stand growth. Tree height was used for initial stand characterization.

While dbh and height measurements can provide information on present stand production and a means to predict future productivity, the capacity of the stand to continue producing is also dependent on stand structure (the distribution of trees by diameter classes). Stand structure changes from year to year due to natural growth, reproduction, and mortality. Any environmental disturbance could produce an effect on these factors. Therefore, to achieve a complete picture of possible ELF field effects on tree and stand production, dbh, height, ingrowth, and mortality are being measured in order to distinguish natural changes from those caused by site disturbances.

In addition to tree productivity in hardwood stands, regeneration studies involving planted red pine are being conducted on the ground, antenna, and control sites. These studies were initiated in response to a need for a larger number of conifers in the ectomycorrhizal studies (Element 6) as well as to address the Michigan DNR concerns about forest regeneration. Since young trees often exhibit rapid growth rates compared to older trees, possible ELf field effects may be more easily detected on seedlings rather than on older trees. In the red pine seedlings, both diameter and height increment are response variables for assessing any possible effects due to ELF fields. Again, as in the case of trees in the hardwood stands, diameter, height, and mortality are being measured.

Hardwoods

Diameter increment is the primary response variable for assessing the effects of ELF fields on the hardwood stands located at the antenna and control sites. Permanently installed dendrometer bands allow continual measurement of incremental growth on each tree in the stand. This information provides a

view of both the total growth in an entire growing season and the rate or distribution of diameter growth over the growing season.

Hardwood stands on both study sites are classified in the *Acer-Quercus-Vaccinium* habitat type (Coffman *et al.* 1983). Those overstory species common to both sites and included in the analysis are northern red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*Populus tremuloides*), and red maple (*Acer rubrum*). A summary of stand information for both sites at the beginning of the 1991 growing season can be found in Table 2.1; the change in average dbh on the study sites for each year since 1984 is given in Table 2.2.

Each analysis will eventually test the overall null hypothesis:

> H_0: There is no difference in the magnitude or the pattern of seasonal diameter increment before and after the ELF antenna became operational.

This hypothesis is addressed through testing of differences between the control and the antenna sites and testing between post-operational years and previous years. The system operated at low levels throughout the growing seasons of 1987 (15 amps) and 1988 (75 amps) and at full power (150 amps) since 1989. Whenever possible, differences between sites and between 1987-1991 and previous years are examined. Tests concerning the rate or the distribution of diameter growth are made using the diameter growth model discussed later in this section. Tests in previous years (Mroz *et al.* 1988) have shown that there are no significant differences in the parameters of the growth model between years or among sites. Comparisons of post-operational years with previous years are in part made by examining residuals of individual tree diameter growth over years and sites. Differences in the magnitude or amount of seasonal diameter growth are examined through the split plot analysis of covariance. The analysis of covariance table used in this study is found in Table 2.3. Since monthly soil nutrient concentrations are a critical covariate, the analysis of covariance reported here is performed on data collected through 1990. An analysis including the 1991 data will be performed following completion of laboratory analysis of the soil samples.

Sampling and Data Collection

To monitor diameter growth on both sites, permanent dendrometer bands were installed in 1984 on all trees greater than or equal to 10 cm dbh. Due to vandalism, 175 new bands were installed on the control site in 1985. On the antenna site the number of study trees was reduced from 209 in 1984 to 197 in 1985 due to a few band failures and a small vandalism incident unrelated to that on the control site. The death of one bigtooth aspen on the control site reduced that sample to 274 trees in 1985. At the start of the 1987 growing season, the trees which

Table 2.1. Summary of hardwood stand information for the antenna and control sites at the beginning of the 1991 growing season.

Species	Average DBH (cm)[b/]	Basal Area Per Hectare (m^2/ha)	Number Bands in 86	Number Bands in 91[c/]	Died in 1991	Number of Stems per Hectare	Site Index	Age (yrs)
Antenna								
Northern Red Oak	24.83	8.51	44	49	0	156	68	52
Paper Birch	20.13	0.96	8	8	0	25	66	60
Aspen[a/]	27.02	2.85	15	15	0	48	68	55
Red Maple	15.64	9.48	129	147	1	467	56	47
Control								
Northern Red Oak	22.02	22.71	174	174	3	552	72	57
Paper Birch	18.02	2.09	38	24	15	76	60	59
Aspen	24.37	6.08	43	40	3	127	65	60
Red Maple	11.96	0.79	15	22	0	70	58	50

[a/] The two aspen species are combined.
[b/] Average DBH includes ingrowth trees for 1987 but not trees which died in 1988.
[c/] Includes trees which grew to larger than 10.0 cm dbh since 1985 which were banded in 1987 but not trees which died in 1988.

Table 2.2. Average dbh (cm) by species and site at the beginning of each year of this study.[a/]

	1984	1985[b/]	1986	1987	1988	1989	1990	1991	1992
Antenna									
Northern Red Oak	22.18	22.45	22.69	23.09	23.36	23.76	23.99	24.05	24.54
Paper Birch	20.02	20.22	20.42	20.56	20.70	20.83	20.93	21.03	21.13
Aspen[c/]	24.59	25.01	25.37	25.67	25.93	26.20	26.49	26.71	27.02
Red Maple	14.87	15.09	15.23	15.33	15.44	15.89	15.98	15.71	15.54
Control									
Northern Red Oak	20.45	20.62	20.82	20.94	21.12	21.58	21.76	21.68	22.03
Paper Birch	16.12	16.23	16.30	16.36	16.41	17.21	17.24	16.79	18.02
Aspen	22.21	22.55	22.82	23.03	23.18	23.47	23.61	23.77	24.37
Red Maple	11.37	11.64	11.85	12.01	12.17	12.28	12.40	12.51	12.62

a/ Only trees banded prior to 1987 are represented here.
b/ Values given for the beginning of the growing season were calculated by adding all previous years growth to diameter taken in 1984.
c/ The two aspen species are combined.

Table 2.3. ANOVA table used for analysis of diameter growth by species.

Source of Variation					
Covariate	Group (A)	# group A covariates	SSC	MSC	MSC/MSE(S)
Site		1	SSS	MSS	MSS/MSE(S)
Error(S)		# trees-2-#covariates	SSE(S)	MSE(S)	
Years		# years-1	SSY	MSY	MSY/MSE(SY)
Site x Years		(1)(#years-1)	SSSY	MSSY	MSSY/MSE(SY)
Covariate	Group (B)	# group B covariates	SSCY	MSCY	MSCY/MSE(SY)
Error(SY)		(#trees-2-#covariates)(#yrs-1)	SSE(SY)	MSE(SY)	

Group A covariates differ by site but not by year, such as soil characteristics.
Group B covariates change from year to year, such as annual rainfall.

had band failures in 1985 on the antenna site, as well as all trees which had become larger than 10 cm dbh since 1984, were banded on both sites (Table 2.1). In 1988, there were three trees on the control site (two paper birch and one bigtooth aspen) which died. This mortality in 1988 occurred on trees which had not grown appreciably since 1984, indicating that they were not very vigorous, and they probably succumbed to climatic stress during the 1988 growing season. In 1989, additional trees which had grown to exceed 10 cm dbh were banded giving a total of 220 trees on the antenna site and 281 trees on the control site at the start of the 1991 growing season (Table 2.1).

Bands were read to the nearest 0.01 inches of circumference at both study sites beginning on April 17 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until October 9 when growth had slowed considerably and over 50 percent of leaf fall had taken place. This provided a total of 26 measurements in 1990.

Progress

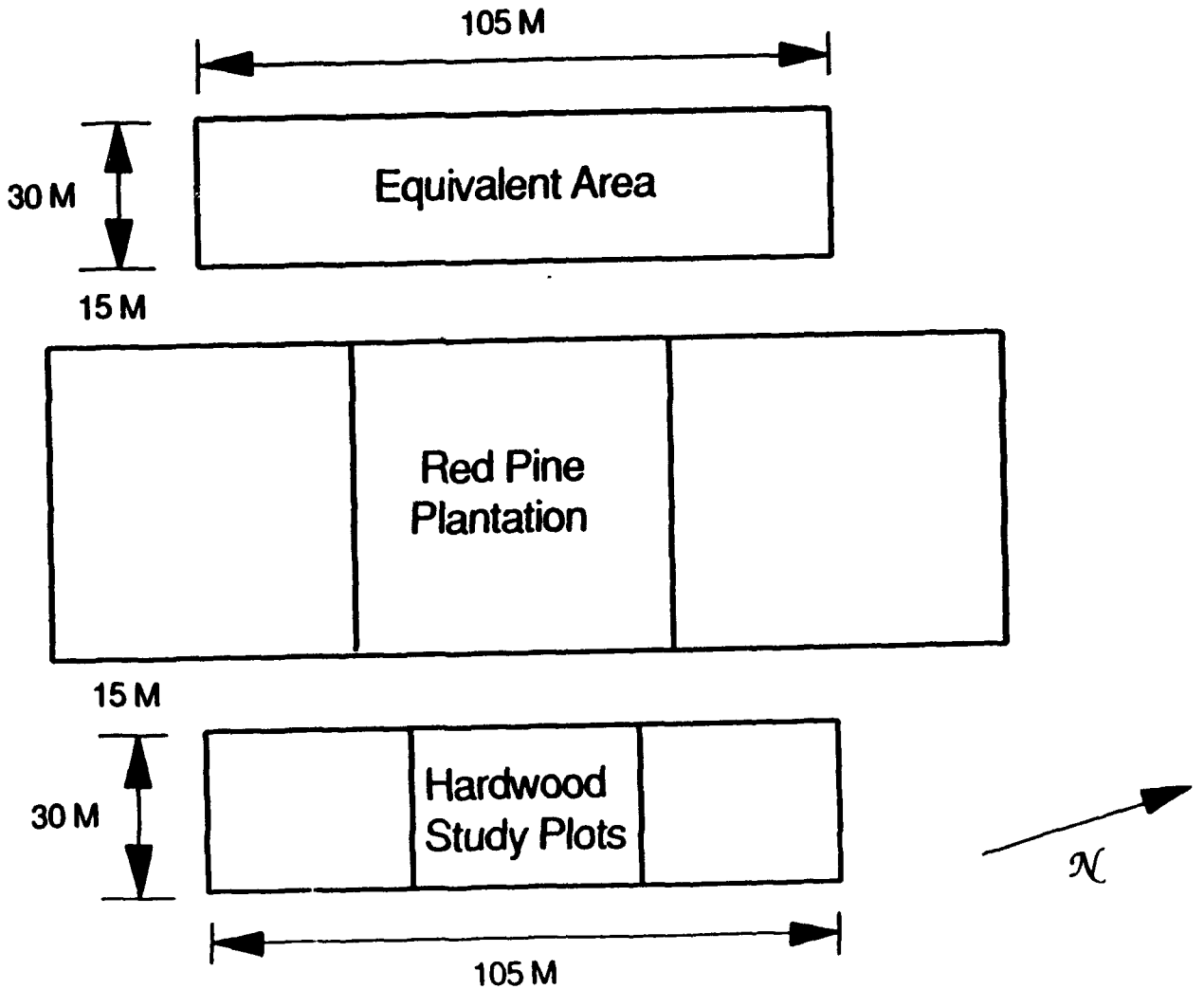
Paper Birch Mortality

Soon after the initiation of dendrometer band measurements in the spring of 1991, it became apparent that a number of paper birch at the control site did not leaf out in the spring. There were 39 banded trees at the control site and 10 banded trees at the antenna site. A total of 23 paper birch (59%) at the control site were dead, 7 (18%) were noticeably declining (as indicated by crown dieback), and 9 (23%) appeared healthy. Eight of the paper birch at the control site which appeared dead later developed a minimal amount of foliage. At the antenna site, no trees appeared dead, 2 (20%) appeared to be declining, and 8 (80%) appeared healthy.

To determine if this mortality was restricted to the measurement plots at the control site or if it was present in the surrounding stand, an area equivalent in size to the measurement plots (30 X 105 m) was surveyed directly across the red pine plantation (Figure 2.1). In that area, there were 134 living and dead birch. A total of 97 (72%) trees were dead and still standing but some of these had been dead for more than one year. A total of 22 (16%) appeared to be in decline and 15 (11%) appeared to be healthy. As a result, it could be concluded that the mortality was not restricted to the measurement plots and was present to an equivalent extent in the surrounding stand.

A similar procedure was followed at the antenna site. There, a total of 137 living and dead paper birch were identified in the surveyed equivalent area. A total of 71 (52%) were dead, 22 (16%) were declining, and 44 (32%) appeared healthy. It is apparent that the mortality is not restricted to the control site but that significant, though less extensive, mortality was also present in the stand surrounding the measurement plots at the antenna site.

Figure 2.1 Map of the paper birch mortality survey plots at the control site.



Paper birch is not a long-lived species. It is not uncommon for pure birch stands to suffer heavy mortality somewhere between 50 and 75 years of age (Eyre 1980) though birch in mixed hardwood stands, such as those on the study sites, often do not decline until later (Marquis *et al.* 1969). Thus, paper birch on the study sites may be reaching the age where natural mortality would be likely though it would not be expected for this to occur synchronously at the two sites without some activity by an external biotic or abiotic agent.

Subsequent discussions with Michigan DNR personnel (R. Heyd, personnel communication) indicated that paper birch mortality was present in a large number of mature stands across northern Michigan. This mortality was associated with activity of the bronze birch borer (*Agrilus anxius*, Gory.) and emergence holes indicating activity of this insect were found later in the growing season in the dead birch at both sites. In his discussion of the bronze birch borer, Anderson (1960) states the following:

> "When dying trees are heavily infested with *Agrilus* the insects are commonly thought to be the cause of tree death. Most of those who have worked on this problem, however, think that these borers are in the dying trees because the host material is suitable and are not the primary cause of tree decadence. Sometimes, however, they do kill trees such as the European varieties of white birch. Droughts also predispose trees to attack by causing temporary partial to complete cessation of radial growth."

Anderson goes on to state that drying and heating of the surface soil causes excessive root mortality and subsequent tree decadence.

Millers *et al.* (1989) report numerous cases of widespread paper birch mortality in the Lake States (Wisconsin in 1979-80, Minnesota in 1979-86, Wisconsin in 1984-86, and in Michigan, Minnesota, and Wisconsin in 1985). In all these cases, insect activity, frost damage, and heavy seed crops have been implicated in the mortality. There were reports of drought and warmer weather being implicated in birch dieback (primarily yellow birch (*Betula allegheniensis*)) in the 1940s (Hawboldt 1947, 1952, Nash and Duda 1951) but these were discounted by some later authors (Clark 1961, Clark and Barter 1958, Redmond 1957).

On the study sites, average annual paper birch diameter growth has been declining since 1984 on the control site and since 1985 on the antenna site (Table 2.4). There was a slight increase in average annual paper birch diameter growth on the antenna site in 1990 and a return to the 1989 growth level in 1991. The diameter growth model residual (Mroz *et al.* 1990) was not different from zero on either site in 1986, 1987, or 1988 but was significantly less than zero ($p=0.05$), indicating a lower than expected growth rate, on both sites in 1989. Though litter production varies from year to year, there was no noticeable

Table 2.4. Average seasonal diameter growth (cm) for tree species on each site for the 1984 through 1991 growing seasons.[a/]

	Sample Size	1984	1985	1986	1987	1988	1989	1990	1991
		cm							
Northern Red Oak									
Antenna	44	0.2778	0.2389	0.1991	0.2710	0.2354	0.2256	0.2258	0.2876
Control	171	0.1707	0.2030	0.1508	0.1823	0.1595	0.1773	0.1561	0.1860
Paper Birch									
Antenna	8	0.2000	0.2038	0.1500	0.1304	0.1132	0.0990	0.1081	0.0990
Control	24	0.1050	0.0765	0.0652	0.0406	0.0419	0.0345	0.0187	0.0280
Aspen									
Antenna	13	0.4133	0.3653	0.2993	0.2355	0.2576	0.2877	0.2205	0.3288
Control	40	0.3386	0.2643	0.2164	0.1529	0.1713	0.1415	0.1204	0.1615
Red Maple									
Antenna	129	0.2163	0.1374	0.1017	0.1130	0.0830	0.0899	0.0952	0.0778
Control	15	0.2667	0.2040	0.1533	0.1768	0.0690	0.1152	0.1272	0.0986

[a/] Only trees banded prior to 1987 are represented here.

decline in litter production on either site until 1990 on the control site (Mroz *et al.* 1990).

The average April-October air temperature on the antenna and control sites is discussed in Element 1. The warmest temperatures were in 1987 and 1988 with 1988 having the greatest number of air temperature growing degree days. Soil temperature at 5 cm follows the same pattern as air temperature. Albert *et al.* (1986) indicate an average May-September air temperature of 15.0°C in this climatic district which roughly corresponds to 12.4°C during April-October. On this basis, 1986-1989 were warmer than normal on the control site while 1987 and 1988 were warmer than normal on the antenna site.

Annual growing season (April-October) precipitation on the study sites varies considerably (Element 1). Albert *et al.* (1986) indicate average May-September precipitation in this climatic district of around 2.0 cm per week, more than was observed on the study sites in any year except 1985. This apparent moisture deficit may be deceiving in that much of the early growing season moisture demand in this region is met by water stored in the soil during snowmelt and the trees are not that dependent on rainfall early in the growing season. Average April-October soil moisture content (Element 1) also varies from year to year but 1986 and 1990 were considerably higher than 1987-89 on the control site and 1990 was considerably higher than 1986-89 on the antenna site. Even though soil moisture percent is greater on the control site than the antenna site, not as much is available to plants due to soil physical properties. Average April-October soil water potential, an indicator of how tightly water is held in the soil, shows that available moisture is much greater at the antenna site (Element 1). At the control site, 1988 and 1989 were the driest years in terms of available soil moisture, even though 1989 was a cooler year than 1988. The combined effects of temperature and moisture are illustrated by the average April-October relative humidity at the study sites (Element 1). The relative humidity at the control site is consistently about 15% lower than at the antenna site. At both sites, relative humidity in 1989 was the lowest observed during the study period.

To summarize, the paper birch mortality at the control site and in the surrounding stands at both the antenna and control sites appears to be a natural phenomenon and not related to antenna activity or measurement activity on the study plots. This conclusion is based on the following:

1. At the beginning of 1991, the paper birch at the antenna and control sites was 60 years old. While this is not yet the age where senesence is expected, these trees are approaching the age where they may be vulnerable to climatic stress and pest/pathogen activity.

2. Recent years, particularly 1987 and 1988, were warmer than normal on both of the study sites while 1988 and 1989 were years with low moisture availability at the control site. Given the sensitivity of paper birch to temperature and moisture

conditions in the surface soil horizons, and the reduced growth rates observed on the study sites during these years, it is likely that these trees were under climatic stress in recent years. This is further evidenced by residuals from the diameter growth model. The trees behaved as expected in 1986-88, even though growth was reduced, but in 1989 growth was reduced by more than an expected amount on both sites, possibly due to the model not adequately accounting for the low moisture conditions.

3. The bronze birch borer was associated with the dying paper birch on the control site (and across Upper Michigan) but it is likely that the trees were vulnerable to insect attack due to their age and recent climatic stress.

In the growth analyses through the 1990 gropwing season which follow, paper birch growth is included though it may be deleted from future reports due to the extensive mortality in 1991. It is also worthwhile to consider the implications of these findings regarding the other species on the study sites. While all species may benefit from reduced competition from the paper birch, it is a relatively minor stand component and this mortality should not result in greatly improved growing conditions for the other trees. Of particular concern is the aspen. Aspen, like paper birch, is a relatively short-lived species (Brinkman and Roe 1975) which is subject to rapid breakup (Fralish 1972) sometime between 60 and 100 years of age. Aspen on the antenna and control sites were 56 and 61 years of age, respectively, at the start of the 1991 growing season. Aspen growth has declined on both sites since 1985 (Table 2.4) but this has been more severe at the control site. Also, the diameter growth model residuals indicated less than expected growth for aspen in 1989 for the first time (Mroz *et al.* 1990). It is possible, therefore, that a similar decline episode may occur for aspen on the study sites in the near future but the trees on the antenna site appear to be less vulnerable than those on the control.

Growth Analysis

Magnitudes and rates of diameter increment were examined for each species. Analysis of tree diameter is approached in two ways. The split plot analysis of covariance is used to determine if there is any change in the magnitude of average yearly diameter growth which may be due to ELF fields. Secondly, regression models were developed in past years (Mroz *et al.* 1988, Appendix C) to further quantify the relationships between tree, site, and climatic variables and tree diameter growth. These models are used to test for changes in both seasonal growth pattern within a year and relationships affecting total annual growth due to ELF fields. Examination of the individual tree diameter growth residuals is conducted to determinee if there have been changes in the effects of tree, site, or climatic variables on individual tree diameter growth and to examine the

effects of the level of ELF field exposure on diameter growth. The modeling analyses use information for all trees, including those banded since 1985. The split plot analysis of covariance only utilizes growth information on trees which have been banded for the entire study period.

Analysis of Total Seasonal Diameter Growth

At present, eight years (1984 through 1991) of diameter increment data have been collected from trees on the study sites. In 1984, first incremental growth was not collected until early June due to a relocation of the control site. Because of this, total diameter increment in 1984 is not derived from dendrometer band data, but from spring and fall diameter tape measurements of individual trees. Also, due to installation and calibration of the ambient monitoring equipment, the climatic variables are not completely available for 1984. For these reasons, the 1984 diameter growth measurements were not included in the analysis of covariance. Monthly soil nutrient concentration proved to be an important covariate for explaining both site and year differences in diameter growth. These data are not yet available for the 1991 growing season; the tree growth information from 1991 will not be incorporated into these analyses until a complete set of covariates is available. Table 2.4 presents the total annual diameter growth by species for each of the eight growing seasons, even though data from 1984 and 1991 are not included in the following analyses.

Results of an intensive variable screening procedure to select covariates to include in the analysis of covariance for each species have been reported previously (Mroz *et al.* 1988, Reed *et al.* 1991). There have been no attempts to refine the set of covariates for each species this year. Since antenna activity has increased, attempts to redefine covariates using information from later years could be confounded with possible ELF field effects on diameter growth. The covariates used are total air temperature degree days through May for red maple and through September for the other three species, July soil potassium concentration for all four species, soil water retention capacity from 5 to 10 cm for red maple, and soil water retention capacity from 10 to 30 cm for paper birch.

An initial analysis of variance, without covariates, was performed for individual tree annual diameter growth for each species. In all four species, there were significant ($p<0.05$) differences indicated in individual tree diameter growth rates among the study years (Table 2.5). There were also significant ($p<0.05$) differences between the study sites for all species except northern red oak. For red maple, there was a significant ($p<0.05$) interaction between site and year. As indicated in previous years, a logarithmic transformation was applied to the northern red oak and red maple data prior to the analyses. An analysis of covariance using the covariates listed previously indicated that there were no differences ($p=0.05$) in individual tree diameter growth between sites for any of the four species.

Table 2.5. Significance levels[a/] for the analyses of variance and covariance of individual tree diameter growth.

Species	Source of Variation		
	Site	Year	Site*Year Interaction
Analysis of Variance (No Covariates)			
Northern Red Oak	.068	.000	.896
Paper Birch	.000	.000	.074
Aspen	.001	.000	.097
Red Maple	.010	.000	.037
Analysis of Covariance			
Northern Red Oak[b/]	.348	.000	.310
Paper Birch	.058	.000	.329
Aspen	.358	.000	.074
Red Maple	.318	.008	.114

[a/] A significance level less that 0.05 indicates a significant difference at p=0.05.

[b/] For northern red oak and red maple, a logarithmic transformation was performed on individual tree diameter growth prior to analysis.

The significance level for paper birch was 0.058 which is much nearer to 0.05 than in previous years. This was due to the reduced growth on the control site prior to the mortality of nearly one-half of the trees following the 1990 growing season. There were differences ($p<0.05$) among years for all four species, but there were no significant ($p=0.05$) site and year interactions for any species.

These results indicate that there was no difference between the individual tree diameter growth rates on the two sites. There were significant differences in individual tree diameter growth rates among the study years which were not accounted for by the covariates. The fact that there was no site and year interaction for any of the four species indicates that the relationship between the individual tree diameter growth rates on the two sites did not change over time. Based on these results, there have been no significant changes in the magnitude of annual individual tree diameter growth in the four study species which could be attributed to the activity of the ELF antenna.

To further investigate the yearly differences in total annual diameter growth for each species, SNK multiple comparison procedures (Zar 1980) were performed for each species. These tests compared the average yearly diameter growth values for each species to determine which years had similar levels of growth. The adjusted total annual diameter growth from the analysis of covariance was ranked by year from least to most as indicated below for each species with years that had similar growth levels denoted by the same letter:

Northern red oak:	1986^{a}	1988^{b}	1990^{bc}	1987^{c}	1989^{c}	1985^{d}
Paper birch:	1990^{a}	1989^{a}	1987^{b}	1988^{b}	1985^{b}	1986^{b}
Aspen:	1990^{a}	1985^{ab}	1989^{b}	1987^{c}	1988^{c}	1986^{d}
Red maple:	1989^{a}	1990^{b}	1986^{c}	1987^{c}	1985^{d}	1988^{e}

There is no clear separation of pre-operational years (1985 and 1986), antenna testing years (1987 and 1988), and years when the antenna operated at full power (1989 and 1990) for any species with the possible exception of red maple. For red maple, 1989 and 1990 were the years with the lowest adjusted total annual diameter growth but the growth in these two years was significantly different. For paper birch, annual diameter growth is reduced in 1989 and 1990. This is due to the reduced growth on the control site in the years preceeding the death of nearly one-half of the trees in 1991. As discussed earlier, this paper birch mortality appears to be unrelated to antenna activity. Additional years with the antenna operating at full power will be needed before a definitive statement can be made but there is no clear indication at this time that antenna operation has had a significant effect of total annual diameter growth for any of the four species.

One of the critical assumptions of an analysis of covariance is that the covariates are independent of the treatments, in this

case the EM field exposure levels. Violation of this assumption implies that the effect of the fields is confounded with the covariates and the interpretation of the results given above is invalid. To test the validity of the analysis of covariance, the correlations between the average plot EM field exposure level and the covariates were calculated. Significant ($p<0.05$) correlations were found between the July soil potassium concentration ($r=-0.43$) and the magnetic field strength and between air temperature degree days through May ($r=-0.52$) and the magnetic field strength.

The fact that two variables are correlated does not imply a cause and effect relationship. In this case, there does not appear to be any reason to expect a causal relationship between the magnetic fields generated by the antenna and air temperature or soil nutrient level. The correlations observed in 1990 are approximately the same as those from 1989 but are less than those from 1988. In any case, the covariates are significantly correlated with the EM field exposure levels and the analysis of covariance of individual tree diameter growth should not be considered a reliable test of the effects of EM fields. The analyses of covariance do not suggest a significant effect due to EM fields but there could still be an effect which is masked by the correlations between the EM field exposure levels and the covariates.

Diameter Growth Model

Many of the relationships between diameter growth and tree, site, and climatic variables can be expected to be nonlinear (Spurr and Barnes 1980, Kimmins 1987). These nonlinear relationships cannot be adequately accounted for in the analysis of covariance described above. In order to supplement the analysis of covariance, diameter growth models for each of the four species were developed (Mroz *et al.* 1988, Reed *et al.* 1991, Appendix C) to further account for the variability in growth between sites and among years. The growth model also provides an annual residual for each tree which can be examined to see if the diameter growth following antenna activation is diverging from patterns seen in previous years; no similar quantity is available for individual trees from the analysis of covariance. Since the seasonal pattern of diameter growth as well as total annual growth could be subject to ELF field effects, the weekly cumulative diameter growth (cm) was selected as the response variable.

Differences in diameter growth observed since 1985 include differences in the timing of growth between sites, differences in the timing of growth among species, and differences in the timing of growth among years (Mroz *et al.* 1986). Since the stand conditions did not change drastically from 1985 through the 1990 growing season, these observed growth differences are largely due to differences between species, climatic differences between years, and physical differences between sites. These differences

have largely been accounted for in the diameter growth models (Mroz *et al.* 1988, Reed *et al.* 1991, Appendix C).

Cumulative diameter growth is broken into the component parts of total annual growth and the proportion of total growth completed by the date of observation. This simplifies the testing for significant effects of ELF fields on tree diameter growth. Cumulative diameter growth to time t is therefore represented by:

CG_t = (Total Annual Growth)(Proportion of Growth to Time t)

This formulation allows the testing of ELF field effects on both the level of total annual growth (TAG) and the pattern of seasonal growth. In the model, total annual growth is further broken into the component parts of potential growth, the effect of intertree competition, and the effect of site physical, chemical, and climatic properties:

TAG = (Potential Growth)(Intertree Competition)
(Site Physical, Chemical, and Climatic Properties)

The degree of intertree competition is dependent on the distances and sizes of neighboring trees. Since the original stand maps extended only to the plot boundaries, the competitors for trees near the boundaries could not be determined. For this reason, only trees in the center 15 m could be utilized for the growth model analyses from 1985 through 1989. In 1989, an additional 10 m buffer zone was mapped around each plot to allow the utilization of more trees in the analyses. These border trees were initially measured in the fall of 1989; the first use of the additional trees is in the comparisons for the 1990 growing season.

The possible effects of ELF fields on total annual diameter growth are investigated by examining the individual tree residuals (observed growth minus the diameter growth predicted by the model) each year. If there is an effect from ELF fields on diameter growth, the residuals should increase or decrease, indicating a divergence from past patterns of growth. Any apparent increase or decrease in residuals can be further investigated by examining the correlations between the residuals and ELF field exposure variables for each site and year. Possible changes in seasonal diameter growth pattern can be examined by looking at the expected pattern of growth from the model and deviations from that pattern in the measurements.

Total Annual Diameter Growth

Differences between the predicted total annual diameter growth and the observed value were obtained by site and year for each species. If there is a change in the way a tree is responding to site or climatic conditions then the model will not perform as well. In other words, the differences between the observed and predicted diameter growth will increase if an

additional factor is introduced which impacts tree growth. Average residual and studentized 95 percent confidence intervals for the average residual are given by site and year for northern red oak in Table 2.6, for paper birch in Table 2.7, for aspen in Table 2.8, and for red maple in Table 2.9. It should be emphasized that the average residuals are not the predicted average diameter growth values but they are the average differences between the diameter growth predicted for each tree and the measured diameter growth.

The differences in the numbers of observations indicated in Tables 2.6-2.9 are due to the inclusion of the mapped trees in the 10 m buffer zone in the calculation of the competition indices for additional measured trees on the study plots. In Table 2.6, for example, there were 49 observations at the antenna site in 1990. This includes the 23 trees measured in previous years plus 26 additional trees the mapping of the buffer zones allowed to be included this year. This means that more than half of the observations used to calculate the average residual are new in 1990 and were not included in the analyses in previous years. This also impacts the calculation of the studentized 95 percent confidence interval. Again from Table 2.6 at the antenna site, the studentized 95 percent confidence interval was calculated by taking the average residual $\pm$ $t_{22,.05}$*0.0229 which equals the average residual $\pm$ 0.0474. In 1990, due to the increased degrees of freedom in the t value and the reduction in the standard error of the residuals due to the increased numbers of trees, the studentized 95 percent confidence interval is calculated by taking the average residual $\pm$ $t_{48,.05}$*0.0183 which equals the average residual $\pm$ 0.0366, a reduction of 23 percent in the width of this interval. This increases the precision of our measure of the average residual and provides greater sensitivity of the evaluations of changes from growth trends predicted by the models.

For northern red oak, the 95 percent studentized confidence interval for the average residual overlaps zero in all previos years with the exception of 1987 at the antenna site (Table 2.6). In 1990, the studentized 95 percent confidence intervals did not overlap zero on either site and, in fact, indicate that the trees on both sites grew more than expected. The confidence interval from the control site was completely included within the confidence interval from the antenna site, indicating that there was no difference between the average residuals from the two sites. This indicates that the trees grew differently in 1990 than previous years but, since the results were similar on the control and the antenna sites, there is no evidence that the ELF fields have impacted total annual northern red oak diameter growth on the study sites.

For paper birch, there was another decrease in the average residual in 1990 at both the antenna and control sites (Table 2.7). The decrease in 1990 was even greater than the one observed in 1989. This is not surprising given the mortality observed in paper birch in 1991 on the measurement plots at the control site and in the surrounding stands at both sites. The studentized 95 percent confidence intervals from the two sites

Table 2.6. Performance of the combined diameter growth model by site and year for northern red oak.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	20	0.0204	0.0251	-0.0321, 0.0776
	1987	22	0.0797	0.0323	-0.0125, 0.1469
	1988	23	0.0250	0.0202	-0.0169, 0.0669
	1989	23	0.0085	0.0229	-0.0389, 0.0559
	1990	49	0.0403	0.0183	0.0037, 0.0769
Control	1986	61	-0.0069	0.0103	-0.0275, 0.0137
	1987	62	0.0135	0.0112	-0.0089, 0.0359
	1988	62	-0.0178	0.0113	-0.0414, 0.0048
	1989	62	-0.0144	0.0084	-0.0309, 0.0021
	1990	177	0.0154	0.0062	0.0032, 0.0276

Table 2.7. Performance of the combined diameter growth model by site and year for paper birch.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	3	0.0191	0.0241	-0.0846, 0.1228
	1987	3	-0.0053	0.0153	-0.0711, 0.0605
	1988	3	-0.0048	0.0207	-0.0939, 0.0843
	1989	3	-0.0345	0.0062	-0.0612, -0.0078
	1990	8	-0.0786	0.0630	-0.2239, -0.0067
Control	1986	10	0.0047	0.0162	-0.0319, 0.0413
	1987	10	0.0007	0.0086	-0.0188, 0.0202
	1988	10	0.0270	0.0208	-0.0200, 0.0740
	1989	9	-0.0162	0.0059	-0.0295, -0.0029
	1990	39	-0.0382	0.0095	-0.0574, -0.0190

Table 2.8. Performance of the combined diameter growth model by site and year for aspen.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	11	0.0282	0.0193	-0.0143, 0.0707
	1987	11	0.0599	0.0227	0.0099, 0.1099
	1988	10	0.1175	0.0175	0.0779, 0.1571
	1989	10	0.0107	0.0225	-0.0402, 0.0616
	1990	15	0.0105	0.0305	-0.0549, 0.0759
Control	1986	30	0.0533	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	-0.0240, 0.0304
	1988	28	0.0033	0.0184	-0.0048, 0.0411
	1989	28	-0.1094	0.0156	-0.1414, -0.0774
	1990	42	-0.0141	0.0120	-0.0384, 0.0102

Table 2.9. Performance of the combined diameter growth model by site and year for red maple.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	70	-0.0019	0.0059	-0.0136, 0.0098
	1987	80	0.0002	0.0064	-0.0125, 0.0129
	1988	84	-0.0771	0.0053	-0.0876, -0.0666
	1989	84	0.0696	0.0049	0.0599, 0.0792
	1990	148	0.0392	0.0048	0.0298, 0.0486
Control	1986	10	0.0307	0.0143	-0.0016, 0.0630
	1987	10	0.0095	0.0129	-0.0197, 0.0387
	1988	10	-0.0852	0.0243	-0.1402, -0.0302
	1989	12	0.0599	0.0138	0.0286, 0.0912
	1990	22	0.0576	0.0123	0.0320, 0.0832

did not overlap in 1990; the residuals from the trees at the antenna site were even lower than those from trees at the control site. While this could be interpreted as implying a posssible reduction in paper birch growth at the antenna site due the antenna activity, the obviously high levels of stress experienced by the trees on both sites since 1987 makes interpretation of these results with respect to antenna activity difficult. Paper birch growth will continue to be monitored in future years and, if the trees on the two sites recover from their stressed condition, the analyses of future behavior should provide a better indication of the effect of the ELF fields on paper birch growth.

In previous years, aspen annual diameter growth residuals at the antenna site had been increasing over time while those at the control site were consistent and not different from zero (Mroz *et al.* 1989). In 1989, the diameter growth residuals decreased at both sites with the studentized 95 percent confidence interval at the antenna site including zero while the confidence interval at the control site was below zero (Mroz *et al.* 1990). This year, the studentized 95 confidence intervals for the 1990 diameter growth residuals from both sites overlap zero and there is a great degree of overlap in the intervals from the two sites (Table 2.8). The difference in the average residuals from the two sites is much less than in previous years though the residual from the antenna site is still greater than the residual from the control site. The ability to include more trees in the 1990 analyses resulted in a 50 percent increase in the number of trees at each site. Whether the return to expected growth patterns in 1990 at the sites can be attributed to the increased sample size or whether it is due to some other unexplained factor, there does not appear to be any evidence of an affect of ELF fields on aspen diameter growth in the 1990 growing season. Given the apparent ELF effects observed in previous years (Mroz *et al.* 1990), results from future years are expected to add greatly to understanding the behavior of aspen diameter growth on the two study sites.

In 1990, as was also true in 1989, the diameter growth residuals for red maple indicate greater than expected growth at both sites (Table 2.9). The studentized 95 percent confidence intervals did not include zero at either site but there was no difference in the average residual between the two sites. At the antenna site, the average diameter growth residual in 1990 was lower than the average residual in 1989, indicating that growth in 1990 was closer to the expected growth than had been the case at the antenna site in 1989. At the control site, the results was very similar between 1989 and 1990. For red maple, therefore, growth was greater than expected at both sites in 1989 adn 1990 following antenna activation but there were not differences in the average diameter growth model residuals at the two sites in either year. This indicates that there is some factor which is unaccounted for by the model which has resulted in increased growth of red maple over the last two years but there is no evidence of any difference between the antenna and

control sites and, by implication, there is no detectable effect of ELF antenna operation on red maple diameter growth.

As in past years (Mroz *et al.* 1990), a further evaluation of the effects of ELF fields on individual tree total annual diameter growth was conducted by examining the expected level of exposure to the magnetic flux generated by the antenna for all banded trees using the methods described in Appendix A. For all four species at the control site, correlations between the 76 Hz magnetic fields and the diameter growth model residuals were less than 0.001 and clearly not significant. At the antenna site, however, the correlation between magnetic flux and northern red oak diameter growth model residual was significant ($r=0.44$, $p<0.05$) as was the correlation between magnetic flux and red maple diameter growth model residual ($r=0.32$, $p<0.05$). The correlations between paper birch or aspen diameter growth model residuals and magnetic field strengths were not significant ($p=0.05$) in 1990. This is in conflict with the results from 1989 when the magnetic fields were significantly ($p<0.05$) correlated with the aspen and paper birch diameter growth model residuals but were not significantly ($p=0.05$) correlated with the northern red oak or red maple diameter growth model residuals. It is not clear why there are these differences between 1990 and previous years. One reason may be the greater number of trees included in the analyses in 1990. In any case, there does not appear to be any evidence that magnetic field strength is significantly related to paper birch or aspen diameter growth model residual. For northern red oak and red maple, the magnetic field strength is significantly associated with diameter growth model residual in 1990 though it was not in previous years. This could be a spurious correlation, it could be due to the increased number of trees included in the 1990 analyses providing a better indication of the true situation, or it could be due to the fact that there is a lag effect in the response of the trees to EM fields. Results from future years will be needed to clarigy this situation, but there is no clear indication of a cause and effect relationship between magnetic field strength and diameter growth model residual for any of the four species.

When examining diameter growth model residuals from individual trees for several years, it is possible that the results in one year could affect the results for following years. All the the analyses conducted above implicitly assume an independence in the values of the diameter growth model residuals from different years. If there is a relationship between the residuals from different years, one would expect residuals from two successive years to be more highly correlated than those that are two, three, or four years apart. A positive correlation between residuals of different years would indicate that a tree which had greater than expected growth in one year would tend to have greater than expected growth in following years. A similar relationship would hold for trees which had less than expected growth. A negative correlation between residuals of different years would indicate that a tree which had greater than expected growth in one year would tend to have less than expected growth the following year. Similarly, a tree which had less than

expected growth in one year would tend to have more than expected growth in the following year.

The correlations between diameter growth model residuals in different years were calculated and averaged by species and site (Table 2.10). A one year lag in the table indicates correlations between successive years (1986 and 1987, 1987 and 1988, 1988 and 1989, and 1989 and 1990). A two year lag indicates correlations between residuals two years apart (1986 and 1988, 1987 and 1989, and 1988 and 1990), a three year lag indicates correlations between residuals three years apart (1986 and 1989, and 1987 and 1990), and a four year lag indicates correlations between residuals four years apart (1986 and 1990). None of the correlations shown in Table 2.10 are significantly different from zero ($p=0.05$). This implies that the implicit assumption of time independence in the diameter growth model residuals made during the above analyses is valid and that there is no need to consider a time dependent structure to these residuals through the 1990 growing season.

Seasonal Growth Pattern

Possible ELF field effects on seasonal diameter growth pattern are examined by using the Kolmogorov-Smirnov procedure to compare the distribution of seasonal growth predicted by the growth model (Mroz *et al.* 1988, Reed *et al.* 1991, Appendix C) to the observed distribution of seasonal growth from each plot each year. If an environmental factor which *is not* accounted for in the growth model is significantly impacting seasonal diameter growth, the observed growth pattern will differ from that predicted by the model.

There were no significant differences between the observed and predicted seasonal diameter growth pattern for northern red oak on either site in 1986, 1987, 1988, (Mroz *et al.* 1990) or 1990. In 1989, there was a significant ($p<0.05$) difference between the observed and predicted seasonal diameter growth patterns on one plot at each site. There is no evidence of a significant effect of ELF fields on the seasonal pattern of northern red oak diameter growth.

In past years there had been some differences between the observed and predicted seasonal diameter growth patterns for paper birch at both sites though there had been more differences at the control site than at the antenna site (Mroz *et al.* 1990). In 1990, there was a significant ($p<0.05$) difference between the observed and predicted seasonal diameter growth pattern on only one plot at the control site. The differences between the observed and predicted seasonal diameter growth patterns for paper birch at the control site may be related to the apparent climatic stress on these trees that was discussed earlier. There is no evidence of a significant ELF effect on paper birch seasonal diameter growth pattern.

There was a significant ($p<0.05$) difference between observed and predicted seasonal diameter growth patterns of aspen at the control site in 1986 and again in 1989 (Mroz *et al.* 1990). There

Table 2.10. Correlations between diameter growth model residuals in successive years by species and site.

Site	Species	Time Lag 1 Year	2 Years	3Years	4 Years
Antenna					
	Northern Red Oak	-0.146	-0.297	-0.034	-0.023
	Paper Birch	-0.013	-0.118	-0.068	-0.300
	Aspen	-0.249	-0.207	-0.027	-0.017
	Red Maple	-0.222	-0.096	-0.122	-0.060
Control					
	Northern Red Oak	-0.189	-0.138	-0.038	-0.136
	Paper Birch	-0.227	-0.133	-0.062	-0.078
	Aspen	-0.076	-0.333	-0.031	-0.060
	Red Maple	-0.262	-0.196	-0.005	-0.037

was a significant ($p<0.05$) difference between the observed and predicted seasonal diameter growth pattern for aspen on only one plot at the antenna site in 1988 and 1989 (Mroz *et al.* 1990) and this was repeated in 1990 on the same plot. This particular plot (plot 2) has only one aspen individual included in these analyses. Since the other two plots at the antenna site showed no significant deviation from the predicted seasonal diameter growth pattern, there is no real evidence of an effect of ELF fields on the seasonal diameter growth pattern of aspen.

There were significant ($p<0.05$) differences between the observed and predicted seasonal diameter growth patterns for red maple on only a single plot at the control site in 1988, on a single plot at the antenna site in 1986, and a different plot at the antenna site in 1988 (Mroz *et al.* 1989). There were no significant ($p=0.05$) differences between the observed and predicted seasonal diameter growth pattern for red maple on any plot at either site in 1989 (Mroz *et al.* 1990) or in 1990. There is, therefore, no evidence of an effect of ELF fields on the seasonal diameter growth pattern of red maple.

Summary

There is no evidence in any of the comparisons conducted in the hardwood growth analyses which indicates an effect of ELF fields on the growth of northern red oak or red maple. There was evidence in past years which was consistent with an effect of ELF fields on aspen diameter growth (Mroz *et al.* 1990) but this was not evident in the analyses of information from the 1990 growing season. There is also some evidence which might indicate an effect on paper birch diameter growth but this is confounded with climatic stress in recent years and the mortality of paper birch at the beginning of the 1991 growing season. This mortality appears to be a natural phenomenon, appearing widely across northern Michigan, which is due to climatic stress in recent years and activity of the bronze birch borer. There is no evidence of any effect of ELF fields on the seasonal pattern of diameter growth for any of the four species at either site. In particular:

1. There were no significant differences ($p=0.05$) between the antenna and control sites in total annual diameter growth for any of the four species. The covariates are significantly ($p<0.05$) correlated with ELF field exposure levels which confuses the interpretation of these results. Due to these associations between the covariates and the ELF fields, the results of the analyses of covariance should not be considered reliable in evaluating the effects of the ELF fields on total annual diameter growth.

2. The diameter growth model was developed for each species to overcome many of the limitations of the analysis of covariance. Possible ELF field effects are examined by determining if the differences between observed and predicted

diameter growth values are increasing or decreasing. For aspen, evidence which suggested a possible ELF field effect in past years was not present in the data from 1990. For paper birch, there is some suggestion of a possible ELF field effect on diameter growth, but this is confounded by the recent climatic stress and mortality of birch on the study plots at the control site. Northern red oak and red maple diameter growth model residuals were both significantly ($p<0.05$) correlated with magnetic field strength in 1990 but not in previous years. There is no clear evidence suggesting an ELF field effect on total annual diameter growth of any of the four species following the 1990 growing season.

3. There are no differences between observed and predicted seasonal diameter growth patterns for any of the four species which are related to ELF exposure levels.

Red Pine

Seedling Growth

Since young trees experience rapid growth rates, possible effects of ELF electromagnetic fields on growth may be more easily detected on seedlings rather than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) Michigan DNR concerns over effects on forest regeneration, 2) the lack of sufficient natural conifer regeneration on the study sites for mycorrhizal studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Thus, construction of the antenna ground through a red pine plantation allows the study trees to be closer to the electromagnetic source than any mature tree plots which require a buffer strip of trees along the right-of-way.

Total height (cm) and basal diameter (cm) increment on the red pine seedlings are the response variables for assessing possible ELF electromagnetic field effects. Measurements made weekly (on seedling height only), every two weeks (on seedling diameter only), and seasonally (seedling height and diameter) allow examination of both the total growth in a growing season as well as the distribution of growth within the season. This study is conducted on the ground, antenna, and control sites. A summary of stand information for the three study sites can be found in Table 2.11. A summary of all average diameters and heights at each study site over the length of the study are found in Table 2.12.

The evaluation of red pine seedling growth is divided into two areas: 1) the determination of annual growth, vigor, and survival, and 2) the evaluation of seedling growth patterns as a function of time. The overall null hypotheses tested in this phase of the study are:

> H_o: There is no difference in the level of seasonal diameter growth of planted red pine seedlings before and after the ELF antenna becomes operational.

and

> H_o: There is no difference in the level or the pattern of seasonal height growth of planted red pine seedlings before and after the ELF antenna becomes operational.

As discussed earlier in the hardwood stand analyses, evaluation of possible ELF electromagnetic fields on height growth is approached in two forms: the level or amount of height growth in a growing season is analyzed through the analysis of covariance while the pattern of height growth within a growing season is described through a nonlinear height growth model. As mentioned earlier, the ELF system

Table 2.11. Summary of red pine stand information for the ground, antenna, and control sites at the end of the 199[illegible] growing season.

Site	Sample Size	Average Basal Diameter (cm)	Average Height (cm)	Average Bud Size (mm)
Ground	132	5.79	211.40	45.65
Antenna	153	6.86	241.32	55.47
Control	181	6.52	263.57	63.58

Table 2.12. Average diameter (cm) and height (cm) for each site at the end of each year of this study.

	Sample Size	Basal Diameter (cm)	Total Height (cm)
Ground			
1984	300	0.450	17.18
1985	170	0.743	22.73
1986	147	1.280	37.33
1987	141	1.880	59.19
1988	137	2.427	90.22
1989	138	3.375	131.41
1990	136	4.440	167.96
1991	132	5.793	211.40
Antenna			
1984	300	0.441	16.80
1985	188	0.701	23.92
1986	184	1.262	40.34
1987	177	2.117	66.55
1988	164	2.794	100.77
1989	158	3.877	146.32
1990	154	5.300	187.79
1991	153	6.863	241.32
Control			
1984	300	0.459	18.96
1985	217	0.792	28.33
1986	211	1.355	50.50
1987	199	2.116	82.37
1988	192	2.706	116.69
1989	183	3.705	159.02
1990	180	5.060	203.81
1991	181	6.520	263.57

has operated at low levels throughout the 1987 (15 amps) and 1988 (75 amps) growing seasons. In 1989 and 1990 the system has operated at 150 amps although in 1989, the system did not operate for the same length of time as in 1990. Each of these analyses examines possible site differences as well as any existing differences between pre-operational levels, intermediate levels, and full-operational levels. The analysis of covariance table used is the same as that found in the hardwood studies (Table 2.3). Development of a nonlinear height growth model from previous year's data (Mroz *et al.* 1988) provides weekly residuals from the model for individual seedling height growth. By examining the residuals, comparisons may then be made between different levels of antenna operation across time as well as any changes due to site or climatic variables. Their effects on the amount and timing of seasonal height growth can then be evaluated. The level or amount of diameter growth in a growing season will only be analyzed through the analysis of covariance.

Sampling and Data Collection

Areas at the antenna, ground, and control sites were whole-tree harvested in June of 1984. These areas were immediately planted with 3-0 stock red pine seedlings at a 1 m by 1 m spacing. This density provided adequate numbers of seedlings for destructive sampling throughout the study period, allowed for natural mortality, and will leave a fully stocked stand when the study is completed. Following planting, 300 seedlings at each site were randomly selected and permanently marked for survival and growth studies. Additional details concerning the establishment of the red pine plantations can be found in past reports (Mroz *et al.* 1985, 1986).

Natural mortality following the first full growing season (1985) was 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control site. This mortality was somewhat high due to the late planting date which resulted in planting shock as well as desiccation of seedlings during handling and planting. In addition, Mroz *et al.* (1988) observed that 61 percent of the apparently healthy seedlings that did not form terminal buds following planting died, which further indicates the inability of some seedlings to adapt to the planting site. Precipitation during 1985 was adequate for seedling establishment and competition around each seedling was minimal. It is unlikely that these environmental factors had a significant effect in causing this mortality. The mortality that occurred in 1985 was not evident subsequent years. Only a few seedlings died during the course of the last six growing seasons (Table 2.12).

Vegetative recovery following whole-tree harvesting in 1984 increased in 1986. This vegetation competed with the

red pine seedlings for physical resources such as moisture, nutrients, and light. Vegetation control was necessary in 1986 to prevent the competing vegetation from affecting the unrestricted growth of the seedlings. In early June of 1986, competing vegetation was mechanically removed from each plantation plot using gas powered weed-eaters equipped with brush blades. This method was successful in releasing overtopped seedlings and essentially eliminating competition in 1986. Since then we have found sufficient carryover effect to suggest that it was not necessary to repeat weed control again, although woody stump sprouts and aspen suckers were mechanically removed in 1989.

For red pine growth analyses, each of the live permanently marked seedlings on each site was measured at the end of the 1984 through 1991 growing seasons and the following information recorded:

basal diameter (cm)
total height (cm)
terminal bud length (mm)
microsite
physical damage
presence of multiple leaders
number of neighboring seedlings

Information on microsite, physical damage, multiple leadered seedlings, and the number of neighboring seedlings was collected for possible use in explaining results of the growth analyses. Microsite described the physical environment in the immediate vicinity of the seedling such as rocky soil surface or proximity to a stump or skid trail. In 1988 this measurement also included whether the seedling was located in a frost pocket or not. This was based on a visual determination of the surrounding topography. Any physical damage to a seedling such as frost or animal damage was also recorded. Some seedlings possess two or more leaders, none of which expressed dominance over the others, and this situation was noted as well. In addition, beginning in 1987, the number of seedlings surviving in neighboring planting spacings was also recorded to aid in describing any future competition for light and moisture between neighboring seedlings. In 1989, the position and the elevation of each seedling has been mapped on a coordinate system; this is used in calculating amounts of exposure and analyzing effects of ELF fields. In order to account for evident competition between seedlings for available resources, in 1990 and 1991 additional measurements were made on neighboring seedlings. These measurements included the distance of each neighbor to the seedling, the neighbor's diameter, height, previous year's growth, and crown width.

To further describe the growth of the red pine seedlings, a subsample of 100 seedlings per site was selected from the permanently marked seedlings for weekly

height growth measurements. These weekly measurements were obtained in 1985 through 1991. Measurements began in mid-April while shoots are still dormant and continued until mid-July when shoot elongation was completed. Measurements (to the nearest 1 mm) were made from the meristematic tip or the tip of the new terminal bud to the center of the whorl of lateral branches.

Progress

Growth Analysis

The two response variables in this segment of the study are height and diameter increment of red pine seedlings. Differences in total seasonal height or diameter increment from site to site or from year to year are analyzed through the analysis of covariance where tree, soil physical and chemical properties, and climatological data are used as covariates. The pattern of height growth in terms of the elongation of the leading shoot during the growing season is depicted through a growth model. This analyses supplements the analysis of covariance to further account for the variability between sites and over time. The model has been developed to describe the pattern of weekly height increment only and will be used to provide an weekly residual for each tree. The residual is examined to determine if current year shoot elongation changes from patterns observed in earlier growing seasons.

Total Annual Height and Diameter Growth

Covariate selection

Separate analyses of covariance examine differences in seasonal height or diameter increment among the three sites as well as from year to year. At this point there are seven years of growth measurements available (1985 through 1991). Previous analyses have indicated the importance of soil nutrient concentrations as covariates to explain both site and yearly differences that occur in the height and diameter growth (Mroz *et al.* 1986). These values are unavailable for the 1991 growing season at this time. Therefore, until 1991 soil nutrient analyses are completed, all growth analyses discussed include data from 1985 through 1990 only. The average seasonal growth for each of these response variables on each site at the end of each growing season are found in Table 2.13. Covariates for analyses on both height and diameter growth were selected based on an intensive variable screening procedure used in previous work (Mroz *et al.* 1988). No modification of covariates has been done;

Table 2.13. Average seasonal diameter growth (cm) and height growth (cm) for each site for the 1985, 1986, 1987, 1988, 1989, and 1990 growing seasons.

	1985	1986	1987	1988	1989	1990
Diameter Growth (cm)						
Ground	0.27	0.53	0.60	0.54	0.95	1.07
Antenna	0.23	0.55	0.86	0.65	1.09	1.41
Control	0.32	0.57	0.76	0.61	1.02	1.33
Height Growth (cm)						
Ground	5.08	14.28	23.75	28.70	41.99	36.64
Antenna	6.61	16.06	26.96	33.53	46.03	41.28
Control	8.34	22.34	31.87	35.02	42.73	43.89

covariate determination was completed using information collected prior to antenna operation.

Annual height growth

Earlier analyses (Mroz *et al.* 1988) have indicated that use of the previous year's site physical and chemical and climatic data explained more site and yearly variation than the current year's data when analyzing annual height growth. For this reason, height growth occurring in 1986, 1987, 1988, 1989, and 1990 coupled with 1985, 1986, 1987, 1988, and 1989 soil physical and chemical properties and climatic data are included in this particular analysis. The use of the previous year's soil physical and chemical properties and climatic data provides results that are consistent with the fact that red pine is a species of deterministic growth. Height growth in any year is strongly related to the size of the terminal bud which was formed under the previous year's site physical, chemical and climatic conditions (Kozlowski *et al.* 1973). The covariates identified from previous work (Mroz et al. 1988) were implemented again in the analyses of covariance. These covariates included average maximum air temperature for the month of June, total Kjeldahl nitrogen in the upper 15 cm of mineral soil during July, and water holding capacity from 10 to 30 cm in the soil.

Prior to analyses of covariance, an analysis of variance (no covariates included) was performed and highly significant differences in height growth were found among the three sites and among the three study years ($p<0.001$). There was also a significant interaction between the study sites and years ($p<0.001$) (see Table 2.14). With the addition of the three above mentioned covariates, existing site and yearly differences in annual height growth were not completely explained ($p<.05$) in the analysis of covariance. A significant site-year interaction also remained, indicating that the relationship between individual tree height growth rates on the three sites was changing over time. When height growths at each site were ranked from the smallest amount to the largest, the ground site always had the smallest amount of height growth each year followed by the antenna site, followed by the control site. This ranking changed once, in 1989, with the antenna site achieving a larger average height growth compared to the control site which ranked second and the ground site which again had the smallest amount of growth. Secondly, at the ground and antenna sites, the total height growth achieved in 1990 was smaller than the respective total in 1989. This was not true for the control site.

The significant time factor is not surprising based on the young age of the seedlings. Considering the typical

Table 2.14 Significance levels from the analysis of height growth (cm) and diameter growth (cm) with and without the use of covariates.

Factor	No Covariates	Covariates
Height Growth (cm)		
Site	0.0000[a/]	0.0020
Year	0.0000	0.0000
Site x Year	0.0000	0.0000
Diameter Growth (cm)		
Site	0.0000	0.1490
Year	0.0000	0.0000
Site x Year	0.0000	0.0000

[a/] A significance level smaller than 0.05 would indicatd significance (p=0.05).

sigmoid growth curve, the seedlings have been in the exponential portion of the curve. One could not expect to see similar amounts of growth from year to year until later in time when growth is slowing and more linear in shape. In order to identify where significant differences in total annual height growth exist among the study sites, a SNK multiple comparison test was conducted using the adjusted total annual height growth from the analysis of covariance (Table 2.15). Height growth on all three sites are significantly different from each other ($p=0.05$) except in 1986 and 1989. In 1986 (a pre-operational year) the ground and antenna sites are not significantly different ($p=0.05$) and in 1989 (a full level of operation, but intermittent time spans) the control is not significantly different from the ground and from the antenna sites ($p=0.05$). There does not appear to be any pattern of significant differences among sites during the pre-operational, intermediate operation, or full operational years at this point.

One assumption in the analysis of covariance is that the covariates are independent of the treatment; in this case, each covariate selected should be uncorrelated with the EM field exposure levels. Correlations were calculated across time between the selected covariates and average magnetic flux (mG) during the growing seasons. Due to the high impact of the previous season's soil physical and chemical properties as well as climate, correlations between EM fields and the previous growing season as well the current growing season were examined. A significant linear correlation ($p=0.05$) was found between the magnetic flux (mG) and total Kjedahl nitrogen in the soil during July of the previous year ($r=-.3869$), as well as for the current year ($r=-.2682$). Total Kjedahl nitrogen values have steadily decreased each study year and at the same time exposure fields have been steadily increasing. The decrease in total Kjedahl nitrogen values from 1985 to 1989 may be due to leaching as discussed by Mroz et al. (1990) and needs further monitoring. However, when 1990 data are included (total Kjedahl nitrogen values are more constant with the previous year's values) the correlation is not nearly as strong ($0.02<p<0.05$) and may indicate that the correlation is not a cause and effect relationship. At this point in time there does appear to be a confounding effect of the exposure fields on the results of the analysis which needs to be further monitored.

Correlations between EM field strengths (magnetic flux (mG)) for each seedling's location and the total seasonal height growth for each seedling were calculated. There was a significant correlation ($p=0.05$) between the magnetic flux (mG) and the seedling's height growth at the antenna ($r=.6339$) and at the control ($r=.5901$) sites. As mentioned last year (Mroz *et al.* 1990), the seedlings are young and, height growth is only now are beginning to level off. This corresponds to increasing EM field strengths over the study

Table 2.15. Significant relationships [a/] in the analysis of covariances on both sites and years for mean seasonal height growths (cm) which have been adjusted by the covariates.

	Ground	Antenna	Control
1990	32.01[e]	37.09[f]	43.34[h]
1989	47.60[i]	52.17[j]	50.60[j]
1988	30.82[e]	36.35[f]	39.46[g]
1987	22.15[c]	25.02[d]	30.96[e]
1986	9.78[a]	11.10[a]	18.46[b]

[a/] Different letters of the alphabet indicate significant differences in adjusted diameter growths at the alpha=0.05 level.

years at the test site. As the level of height growth continues to level off, these correlations need to be examined further.

At this point time, significant differences ($p=0.05$) do exist among the three sites and among all growing seasons, however, the amount which can be attributed to ELF fields and the amount which is due to the biological growth trends of young seedlings is not apparent at this time.

Annual diameter growth

In the diameter growth analyses, the current season's site physical, chemical and climatic data explained more site and yearly variation than the information from the previous season. This is consistent with the physiological nature of the seedlings. Thus, in the diameter growth analyses, average annual growth from 1985 through 1990 were used in the analyses.

The four variables explaining the greatest amount of variation for this analysis of covariance were: air temperature degree days through August (on a 4.4^{o} basis), total Kjeldahl nitrogen in July, minimum air temperature in May, and available water at 10cm in the month of August. The selection of climatic variables is consistent with the fact that cambial growth begins a little later than shoot elongation (which begins in mid-April) and is only two-thirds completed when shoot growth ceases (end of July). The need to include variables tc account for soil nutrient differences and possible moisture stresses is also consistent with other covariate selections.

Initial analysis of variance (without the use of covariates) found highly significant differences among sites and among study years ($p<0.0001$). There also was a significant interaction between study sites and years ($p<0.0001$) indicating that the trends in growth on the sites were not constant from year to year (Table 2.14).

With the addition of these covariates, site differences were accounted for ($p=0.1490$), but yearly differences ($p<0.001$) and a site-year interaction ($p<.001$) still remained (Table 2.14). Because of the existing differences, SNK multiple comparison tests were employed to examine the adjusted diameter growths from the covariate analysis on each site during each study year. Table 2.16 depicts the significant differences ($p=0.05$) among the sites and among the study years. During the 1985 and 1986 pre-operational study years, the three sites were not significantly different ($p=0.05$) from each other, however in 1987, also a year of low- level operation, all three sites were significantly different ($p=0.05$). During the years when the ELF fields were in an intermediate phase of operation (1988 and 1989 (full power at intermittent times), the control site was not significantly different ($p=0.05$)

Table 2.16. Significant relationships [a/] in the analysis of covariances on both sites and years for mean seasonal diameter growths (cm) which have been adjusted by the covariates.

	Ground	Antenna	Control
1990	1.0490^{fg}	1.3823^{i}	1.2714^{h}
1989	0.9644^{f}	1.1174^{g}	1.0468^{fg}
1988	0.5488^{b}	0.6648^{cd}	0.6055^{bc}
1987	0.5958^{bc}	0.8370^{e}	0.7014^{d}
1986	0.5417^{b}	0.5785^{bc}	0.5724^{bc}
1985	0.3354^{a}	0.2946^{a}	0.3790^{a}

[a/] Different letters of the alphabet indicate significant differences in adjusted diameter growths at the alpha=0.05 level.

from either test site. In 1990, the first year of complete operational power, all three sites were again significantly different ($p=0.05$). The pattern of differences in 1990 was a repeat of that in 1987. This fact and the fact that the control was not significantly differnt from either test site during transitional levels of operation suggests that ELF fields may not be the contributing factor in the existing differences in diameter growth. Zhang's work (1991) with redpine biomass found existing site differences were due to site characteristics instead of ELF fields which would corroborate these results.

As discussed elsewhere, the covariates selected must be independent of EM fields. Correlations were calculated across time between exposure levels (magnetic flux (mG)) and each year's current covariate values. There was a significant correlation between the magnetic flux (mG) and the minimum air temperature in May ($r=-.3585$, $p<0.01$). There also was a slightly significant correlation ($p<0.05$) between the magnetic flux (mG) and accumulated air temperature degree days (4.4^{o} C) through August ($r=-.2821$) and total Kjedahl nitrogen in the soil during July ($r=-.2682$). Both air temperature measures have steadily decreased across the years of study with the exception of 1988 when values increased. This decrease corresponds to a continual increase in EM field strengths. Without a more varied pattern of comparisons, the violation of the assumption of independence can not be completely assumed at this point.

Correlations between EM field strengths (magnetic flux (mG)) for each seedling and the total seasonal diameter growth for each seedling were calculated. There was a significant positive correlation ($p=0.05$) between seedling diameter growth and the magnetic flux at the ground site ($r=.4029$), the antenna site ($r=.4642$) as well as a small correlation at the control site ($r=.0945$). As discussed in the height growth analysis, the correlations may not be purely mechanistic because there is a steady increase in diameter growth for young seedlings which is expected, but it is in conjunction with a steady increase in the power of the ELF fields.

Seasonal Pattern of Height Growth

Height growth models based on incremental seasonal growth of the leading shoot were developed (Jones et al. 1991). Possible ELF field effects were examined through the residuals from the growth model (observed height growth minus predicted height growth) and compared by site and each year to determine if they remain the same, increase, or decrease. They also evaluate changes that might occur in the pattern or timing of seedling height growth among the

three study sites or from year to year (Jones *et al.* 1991 and Mroz *et al.* 1988). The model is comprised of two components. Previous work by Perala (1985) found that climatic conditions were more useful predictors and could explain much of the variation in the timing and the amount of shoot elongation among sites. In this study air temperature degree days (on a 4.4° C basis) is the first component. To further explain the variation in the system a second component was added to the model. A negative exponential component modifies the expected growth based on soil water tension (Zahner 1963). The model form is as follows:

$$g_t = \left[\left(1 - e^{-b_1 * ATDD_2}\right)^{b_3} - \left(1 - e^{-b_1 * ATDD_1}\right)^{b_3}\right] * (TGRO) * \left(e^{b_4 * (MT - .101)}\right)$$

where

g_t	=	amount of shoot growth (0.1 cm) occurring in week t
TGRO	=	expected total shoot growth (0.1 cm) in the growing season
$ATDD_1$	=	air temperature degree days (4.4° C) to the beginning of week t
$ATDD_2$	=	air temperature degree days (4.4° C) to the end of week t
MT	=	average soil water tension for week t (if actual soil water tension is less that .101 -MPa, mt was set to .101 -MPa for model development)
b_1, b_2, b_3	=	estimated coefficients for air temperature degree days component
b_4	=	estimated coefficient for moisture stress component

Table 2.17 contains the values for the estimated coefficients.

Table 2.17. Coefficient estimates for the red pine height growth model.

	Coefficient Estimate	Asymptotic 95% Confidence Interval
b_1	0.0069	(0.0068, 0.0070)
b_2	1.7595	(1.5262, 1.9928)
b_3	0.4024	(0.3633, 0.4413)
b_4	-1.7601	(-2.1119, -1.4083)

The exponent

$$b_2 * TGRO^{b_3}$$

is based on the concept that the duration of shoot growth varies with the amount of total seasonal growth (Perala 1985); as total shoot growth increases, the duration of growth increases as well. Tests show this to be highly significant and applicable to the study sites.

The height growth model provides an weekly residual for each seedling at each site each year where the residual is equal to observed individual tree height growth minus predicted individual tree height growth. If there is any change attributable to EM fields in the height growth from previous years, the residual will either increase or decrease. Although the cumulative curves may mask any possible absolute differences, the advantage in standardizing is that established proportions of growth may be examined. Examination of the residuals from 1986 through 1990 at each study site found no significant differences ($p=0.05$) between the observed proportions and the predicted proportion of seasonal height growth (Table 2.18). Based on this analysis, there is no indication that ELF fields are affecting the height growth of red pine.

As discussed earlier with the hardwood diameter growth residual analysis, the independence of the redpine height growth residuals with respect to time needed to be examined. The correlations between seedling height growth residuals were calculated and averaged by site (Table 2.18). A one year lag compared the correlations between successive years (1986 and 1987, 1987 and 1988), 1988 and 1989, and 1989 and 1990). Similarly, a two year lag compares correlations which are two years apart, a three year lag compares correlations which are three years apart, and a four year lag compares correlations which are four years apart. None of the correlations for any of the time lags at the ground site were significantly different from zero ($p=0.05$). At the antenna and control sites all but one set of correlations were not significantly different from zero ($p=0.05$). The two year time lag (correlations of residuals between 1986 and 1988, 1987 and 1989, and 1988 and 1990) were significantly different from zero ($p<0.05$) for both. Although this violation has occurred and needs to be monitored, there does not seem to be a need to consider a time dependent structure for these residuals through the 1990 growing season.

Possible changes in height growth patterns may also be evaluated through correlation analysis with EM field exposure variables. Each seedling's position was mapped and EM field strengths (magnetic flux (mG)) were calculated for individual seedlings. Correlations were calculated between

Table 2.18. Autocorrelations for one, two, three, and four year lags at the ground, antenna, and control sites in 1985 through 1990.

	Ground	Antenna	Control
One Year Lag	-0.0164	-0.0690	-0.0575
Two Year Lag	-0.2005	-0.2605*	-0.2277*
Three Year Lag	-0.1119	-0.1220	-0.1388
Four Year Lag	-0.1712	-0.0485	-0.0759

* The correlation was significant at the p=0.05 level.

the residuals from the height growth model and the strengths of EM exposures to each seedling across the five years of study. Significant correlations (p=0.05) were found between the residual and the magnetic flux (mG) at all three of the study sites. To determine if these significant correlations were distance related, correlations were run for 1990 data only and no significant correlations (p=0.05) were found at any of the three study sites as was also true with in the previous year's analyses (Mroz *et al.* 1989).

The Kolmogorov-Smirnov procedure was employed to examine if ELF fields affected the seasonal height growth pattern. Differences in the distribution of observed cumulative growth percentage and that predicted by the growth model were calculated for each plot at each site for the 1986 throught the 1990 growing seasons. If an enviromental factor which is not accounted for in the growth model significantly impacts seasonal height growth, than the observed growth pattern will differ from the predicted and the difference between the two willl be significantly different from zero. Figures 2.2, 2.3, and 2.4 illustrate the observed and predicted cumulative growth percentages at each site for the 1990 growing season. There were no significant differences (p=0.05) between the observed and predicted distributions of growth on any plot at any site during any year. From the correlation analysis and the K-S tests, it appears that ELF fields have had no significant impact on the pattern or distribution of seasonal height growth through the 1990 growing season.

Summary

1. At this point, diameter growth differences do exist and these differences can not be assumed to be independent of the ELF fields. However, there does not appear to be a pattern associated with the significant differences found: no significant differences were found in pre-operational years, but at low levels of operation differences in sites occurred in 1987, but not in 1988 or 1989, and at full power in 1990, differences again occurred. The amount of impact on diameter growth which can be attributed to ELF fields and the amount which is due to the biological growth trends and site characteristics is not completely clear yet.

2. There are significant differences (p=0.05) in height growth among the three sites, and as with diameter growth analyses, these differences can not be assumed to be independent of ELF fields. The results from the growth model do suggest that we may be reaching the point where a linear model (analysis of covariance) may not be appropriate for the problem. This relationship may be expected to be nonlinear and if this is the case, based on the height

Figure 2.2

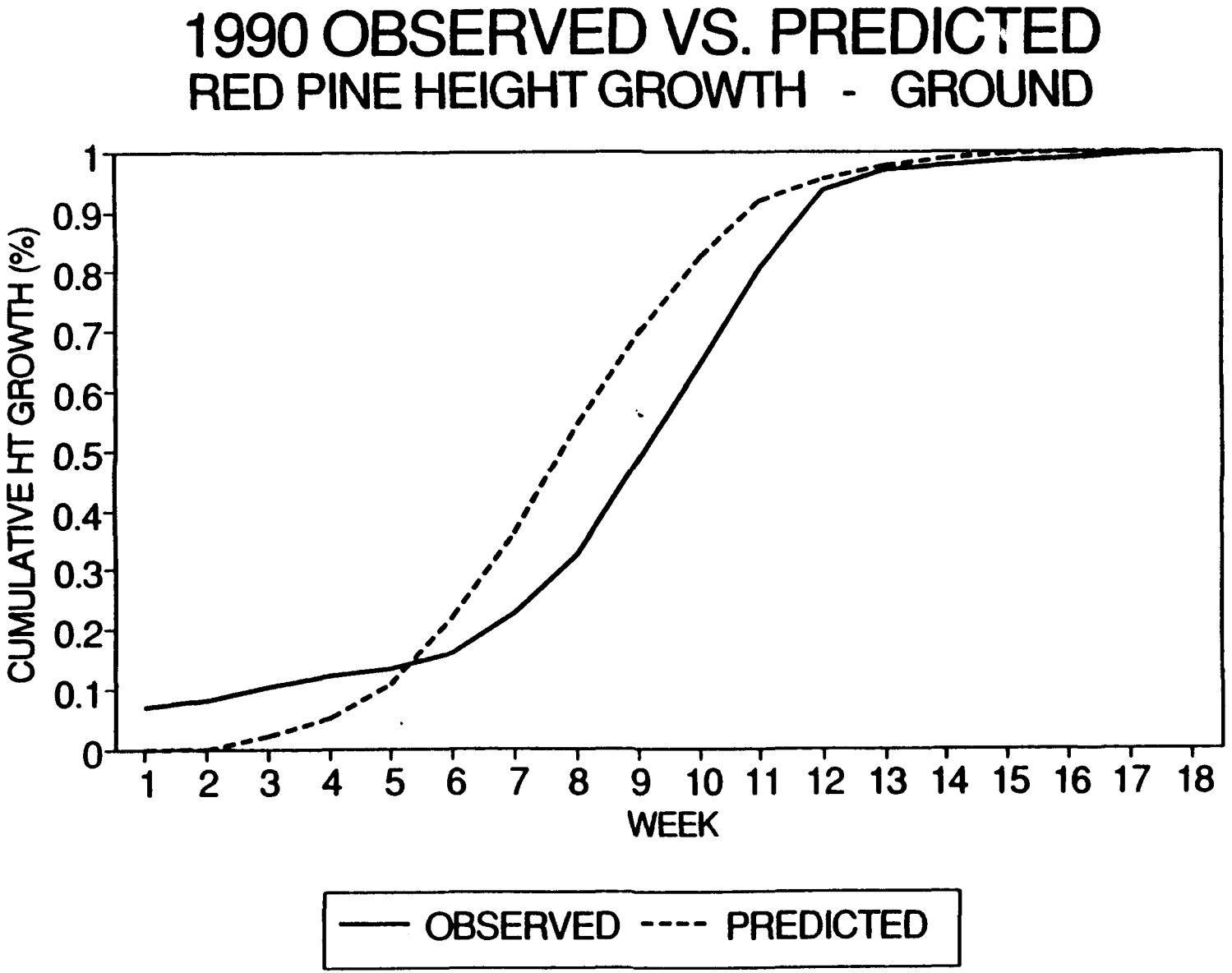

1990 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH - GROUND
CUMULATIVE HT GROWTH (%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
WEEK
OBSERVED
PREDICTED

Figure 2.3

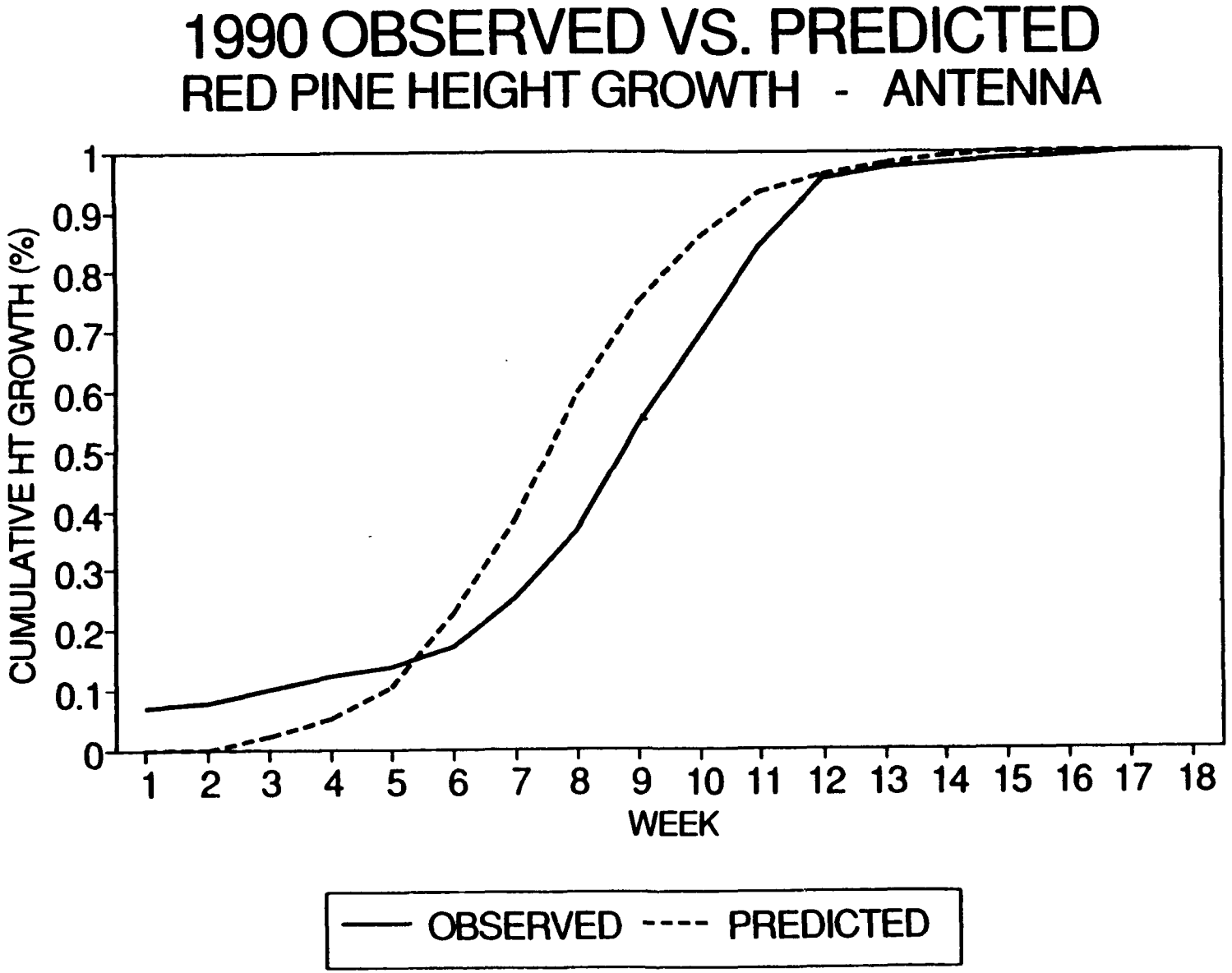
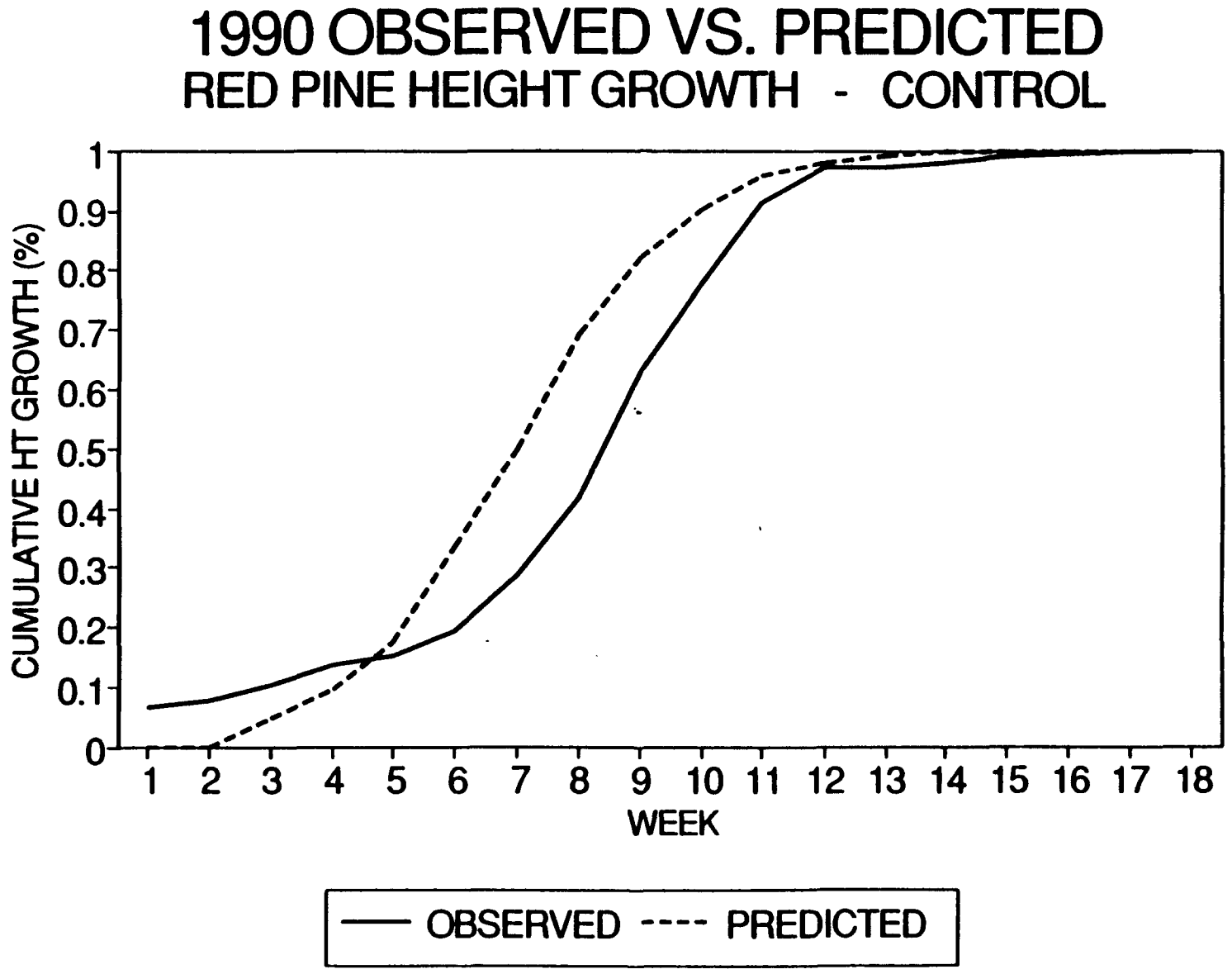

1990 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH - ANTENNA
CUMULATIVE HT GROWTH (%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
WEEK
OBSERVED
PREDICTED

Figure 2.4


1990 OBSERVED VS. PREDICTED
RED PINE HEIGHT GROWTH - CONTROL
CUMULATIVE HT GROWTH (%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
WEEK
OBSERVED
PREDICTED

growth model analysis there are no effects on height growth which can be attributed to ELF fields at this time.

3. A height growth model was developed to supplement the analysis of covariance. Effects due to ELF fields were examined through a comparison of growth model residuals across time and among sites. A lack of significant differences ($p=0.05$) in these residuals both across time and among sites suggests that the ELF fields have no affect on the height growth of the red pine seedlings.

4. Results from the Kolmogorov-Smirnov test indicate that there is no difference between the observed and predicted seasonal height growth patterns through the 1990 growing season.

Leaf Water Potential

Leaf water potential (LWP) is a measure of the internal moisture status of plants and can be a useful measure of overall physiological condition. The overall objective of the red pine LWP study is to quantify the LWP/growth relationship prior to and after activation of the ELF antenna and evaluate the usefulness of LWP as a covariate in the growth analysis of red pine.

Optimum tree growth is dependent on many factors such as healthy root systems which allow adequate uptake of water and nutrients. Similarly, the aboveground biomass must function properly to translocate water and nutrients from the roots to provide photosynthate for growth. A physiological change that would affect the function of the root system and aboveground biomass may also affect the growth of the plant. Such changes may affect the internal moisture status. Thus, changes in LWP may indicate changes in physiological processes that affect plant growth.

Leaf water potential can also be used to help explain growth differences between sites. Site characteristics such as soil physical and chemical properties, microsite, water holding capacity, and climate have an effect on the growth of red pine. Because red pine exhibits relatively little genetic diversity, seedling growth expresses the potential of a site to provide optimal conditions for growth. The quality of the site is thus reflected in the growth of the seedling. If site quality is not optimum, physiological growth is also not at an optimum level and this may be reflected by LWP.

Finally, LWP values can be used to indicate moisture stress during periods of drought. Extended drought can reduce water uptake and reduce growth and survival of red pine seedlings. The LWP values may help explain differences in year to year growth that are due to drought conditions.

Therefore, LWP reflects the integrated effects of physiological processes and environmental conditions on seedling growth and will be evaluated as a potential covariate in the red pine growth studies.

Sampling and Data Collection

LWP sampling was conducted in years 1984 - 1991. The red pine seedlings were planted in June 1984 and became established during that growing season and in 1985. LWP values (MPa) were more negative in 1984 than in subsequent years due to planting shock and do not accurately reflect LWP of established seedlings. Furthermore, ambient monitoring data are not available for 1984 for use in covariate analysis. In 1985, LWP measurements in May and September were conducted under very cold conditions resulting in frozen xylem water and artificially low LWP values. In addition, LWP measurements were collected monthly in 1985 rather than biweekly as in 1986 - 1991. The 1985 data could not be easily compared to

subsequent years when measurements were made biweekly. Therefore, the analysis of LWP presented here will include years 1986-1991.

Sampling in 1991 was conducted biweekly beginning on May 22 and continuing until August 27 at the ground, antenna, and control sites. Sampling was not conducted after this time due to cold temperatures at the scheduled time of sampling and subsequent frozen xylem water; this results in low LWP values that are not an accurate reflection of seedling moisture status. On each sampling date, fifteen actively growing red pines were randomly selected from each site. A one year old needle was cut from each red pine in the pre-dawn hours and immediately placed in a pressure chamber to determine LWP (Richie and Hinckley, 1975). During the daylight hours prior to LWP determination, basal diameter, shoot elongation, total height, and current year needle elongation were measured. The aboveground portion of each sample tree and a portion of the root system were removed from the site the afternoon following LWP determination to obtain aboveground biomass and mycorrhizae counts.

Topographic maps of each plot were developed in 1989 to further describe microsite variation. Computer interpolation of the elevation data then provided a method to assign an elevation to each sample tree provided its location on the plot was known. Because tree location for the sample trees is not available prior to 1988, elevation data are available only for years 1988-1991.

Progress

Leaf water potential values varied between -.21 and -1.06 MPa in 1991 (Figure 2.5 and Table 2.19). With the exception of June 4 at the control site, LWP values are relatively high (low stress). Becker *et al.* (1987) reported

FIGURE 2.5

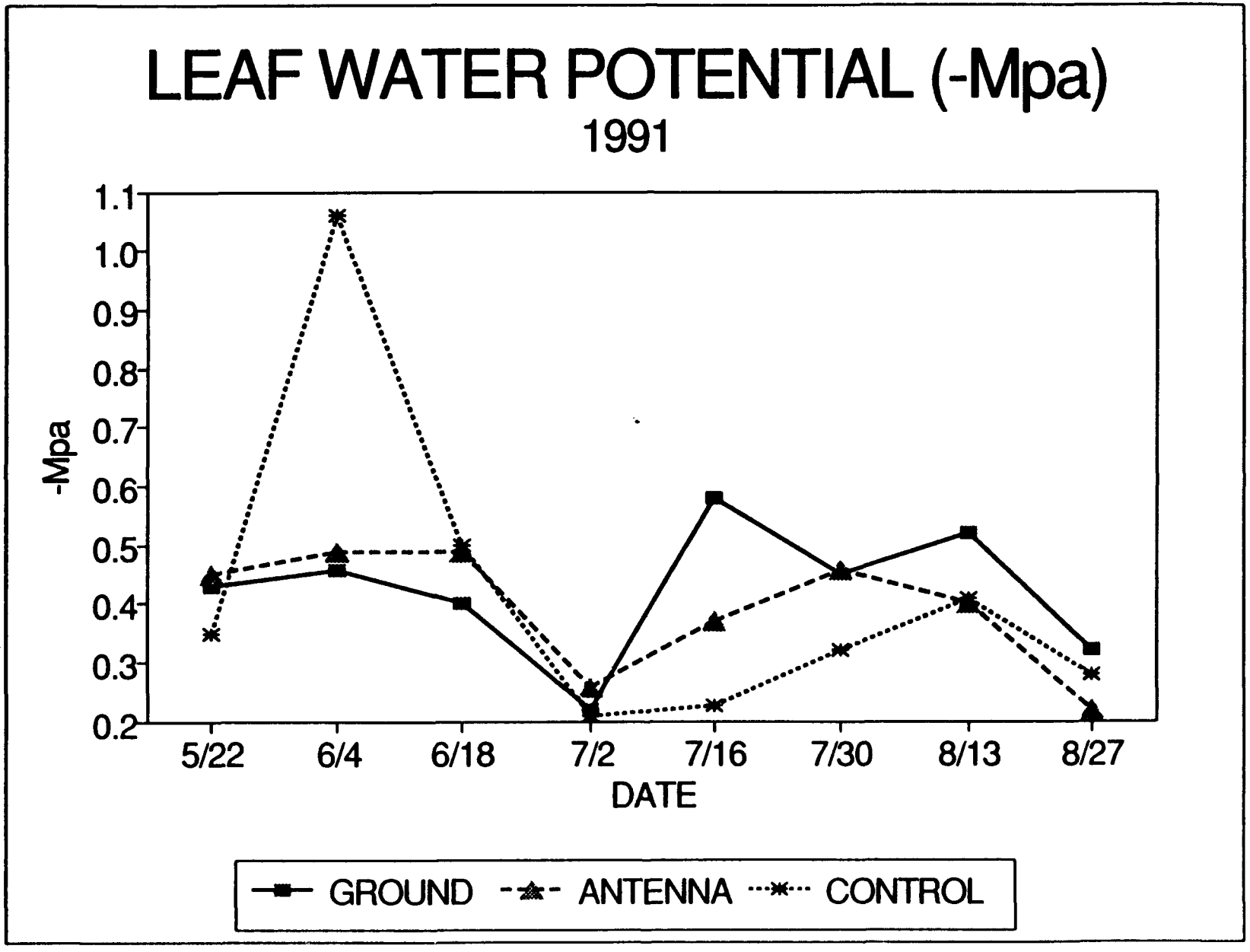

LEAF WATER POTENTIAL (-Mpa)
1991
-Mpa
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
5/22
6/4
6/18
7/2
7/16
7/30
8/13
8/27
DATE
GROUND
ANTENNA
CONTROL

Table 2.19. Average leaf water potential, 1991 (-Mpa N=15.

Date	Ground		Antenna		Control		Overall
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std Dev.	
	---------- -MPa ----------						
5/25	.43	.22	.45	.26	.35	.25	.41[b]
6/5	.46	.13	.49	.16	1.06	.32	.67[c]
6/19	.40	.12	.49	.15	.50	.14	.46[b]
7/3	.22	.10	.26	.10	.21	.09	.23[a]
7/17	.58	.21	.37	.23	.23	.11	.39[b]
7/31	.45	.22	.46	.12	.32	.12	.41[b]
8/14	.52	.21	.40	.21	.41	.21	.44[b]
8/28	.32	.21	.22	.13	.28	.08	.28[a]
Overall	.41[x]		.39[x]		.42[x]		

Values followed by the same letter are not significantly different (p=0.05).

that LWP values ranging from -.80 to -1.1 MPa did not produce measurable reductions in red pine seedling growth. LWP means for all measurement dates were within or above this range.

Analysis of variance was conducted in order to test differences between LWP and measurement dates and sites in 1991. Significant differences (p=0.05) were found between measurement dates and in the date by site interaction but no significant differences were found among sites. The differences found between measurement dates and the interaction between sites and dates have also been reported in the annual reports for all previous years of the study (For example, see Mroz *et. al.* 1990). Because these differences were also found in ELF pre-operational years, we can conclude the ELF electromagnetic fields have had no detectable effect on LWP for these factors.

The combined data for years 1986-1991 were then examined through analysis of variance to evaluate LWP differences between sites and years. The design and ANOVA table for this analysis are presented in Table 2.20.

Table 2.20 Anova table for the analysis of 1986 - 1991 leaf water potential data.

Source of Variation	df	SS	MS	F-Ratio
Year	5	SS(Y)	MS(Y)	MS(Y)/MS(E1)
Date w Year (E1)	42	SS(E1)	MS(E1)	MS(E1)/MS(WR)
Site	2	SS(S)	MS(S)	MS(S)/MS(E2)
Site by Year	10	SS(SY)	MS(SY)	MS(SY)/MS(E2)
Date w Year by Site (E2)	117	SS(E2)	MS(E2)	MS(E2)/MS(WR)
Within + Residual (WR)	1830	SS(WR)	MS(WR)	

w = within

LWP is being considered as a possible covariate in the red pine growth analysis. Therefore, we must determine whether LWP is independent of ELF fields. This can be accomplished by analysis of covariance using climatic variables as covariates. We have assumed if covariates can explain these differences, LWP is independent of ELF fields. As discussed earlier, 1985 LWP data was not included in the analysis reported here. Therefore, it was necessary to re-evaluate ambient and site variables as potential covariates for years 1986-1991. Regression analysis was conducted to select variables that explained significant variation in LWP. Climatic variables selected by the regression analysis were average daily air temperature, total precipitation between measurement dates, and average daily minimum relative humidity. Linear correlation coefficients between each of these variables and LWP are found in Table 2.21.

Table 2.21. Correlations between LWP and ambient variables selected by regression analysis.

Variable	Correlation
Average daily air temperature (^{o}C)	.30*
Precipitation between measurement dates	-.13*
Average daily minimum relative humidity	-.24*

* Significant at p=0.05

LWP was weakly but significantly correlated to each ambient variable. These variables were then used as covariates in the analysis of covariance for LWP. With the inclusion of the 1991 LWP data in the analysis, no significant differences were found among sites or in the site by year interaction. However, significant differences among years were found for the first time since the study began (Table 2.22).

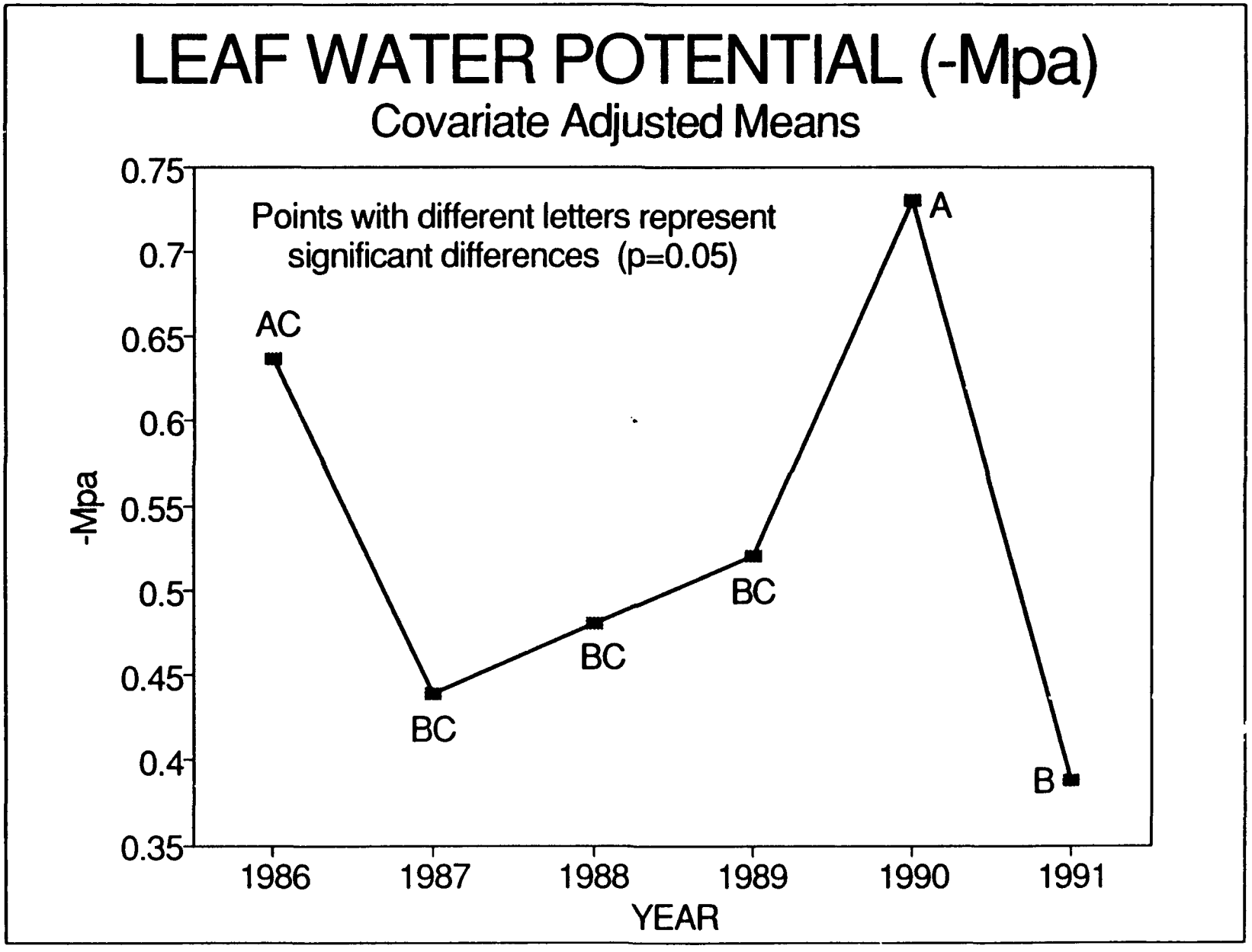
Table 2.22. Significance levels from analysis of covariance for LWP, 1986 - 1991.

Factor	P-value
Site	.883
Year	.002
Site by Year	.273

The covariates that explained year differences in the past did not explain yearly differences when the 1991 data was included in the analysis. The differences among years were found when LWP was relatively low (more stress) in 1986 and 1990, and when it was relatively high (less stress) in 1991 (Fig. 2.6). The reason that ambient variables did not explain yearly differences is unclear. The literature indicates that a strong relationship exists between LWP and soil moisture and temperature (Nambier *et. al.* 1979, Hinckley *et. al.* 1978, Fahey and Young 1984, and Teskey *et. al.* 1984). However, from year to year, we consistently find LWP only weakly but significantly correlated to these variables. It appears that the level of soil moisture was such that over the duration of the study (or at least on LWP measurement dates) changes in soil moisture did not produce pronounced changes in LWP. Average yearly soil moisture of the LWP measurement dates was at least 10 percent. Sucoff (1972) showed that for red pine in Minnesota, soil moisture fell below 10 percent before large decreases occurred in LWP (more stress). Thus, it appears that the yearly differences found in LWP are not directly related to drought.

In a review of water relations in tree species (Abrams 1988), several studies showed seasonal osmotic pressure, which is related to LWP, varied significantly in non-droughted plants. In addition, phenological events such as bud swelling, shoot elongation, and bud initialization and other environmental factors not related to drought also had a pronounced effect on osmotic pressure (Columbo 1987, Abrams, 1988). It seems likely that some of these factors may also be affecting LWP among and within years. In 1991 for example, average daily soil moisture was greater than 12 percent on each of the LWP measurement dates and yet significant differences were found among dates, especially for June 4 at the control site. In such situations, climatic variables may

FIGURE 2.6


LEAF WATER POTENTIAL (-Mpa)
Covariate Adjusted Means
Points with different letters represent
significant differences (p=0.05)
AC
BC
BC
BC
A
B
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
-Mpa
1986
1987
1988
1989
1990
1991
YEAR

operate in combination with physiological processes and other environmental factors to initiate a response in LWP. Identifying potential relationships of LWP with phenological stage may be helpful in explaining yearly differences.

Multiple range tests indicate that LWP in ELF operational years 1990 and 1991 is not significantly different ($p=0.05$) than in ELF pre-operational years 1985 and 1987-1989 respectively (Fig. 2.6). This indicates that ELF electromagnetic fields have not had a detectable effect on red pine LWP. Our work with climatic and site data will continue in the coming year. In addition, we will attempt to identify non-drought related factors which might be causing changes in LWP.

Red Pine Foliage Nutrients

The macronutrients (N,P,K,Ca, and Mg) are important constituents of plant tissues, catalysts in biochemical reactions in plants, osmotic regulators in plant cells, and regulators of plant cell wall permeability (Kramer and Kozlowski 1979). Thus an adequate supply of macronutrients is needed by plants to remain healthy and complete a normal life cycle (Binkley 1986, Kramer and Kozlowski 1979). Healthy individuals of a given specie which receive adequate supplies of nutrients will generally exhibit (at a given developmental stage and time of the year) relative consistent macronutrient concentrations and ratios in a specific type of tissue (Ingestad 1979). This consistent relationship among the nutrients primarily reflects the biochemical requirements which are determined by the genetic composition of the individual plant specie. However, the amounts of biochemical constituents and thus macronutrients change when the plants are stressed by either natural or anthropogenic sources. Often these changes in the biochemistry of the plant are evident long before external signs of the stress are manifested (Margolis and Brand 1990). Given the importance of the macronutrients to plant health and the sensitivity of nutrient concentrations in plant tissue to plant stress, macronutrient concentrations in plant tissue would appear to be a valuable indicator of plant responses to ELF electromagnetic radiation.

Foliar nutrient analysis is the most widely used type of tree tissue analysis because foliage contains the highest concentrations of nutrients in the tree and is the active area of photosynthesis (Mead 1984, Pritchett and Fisher 1987). Thus sampling of red pine foliage and subsequent macronutrient analysis is performed annually to determine 1) whether ELF fields can affect the nutrition of the red pine seedlings and 2) whether red pine foliar nutrient status is related to red pine growth rates. The following hypothesis is used to meet the goals stated in the first objective. Objective 2 will be addressed later after hypotheses related to the growth rates of the red pine and objective 1 has been answered.

> H_o: There is no difference in the foliar nutrient concentrations of red pine seedlings before and after the ELF antenna becomes activated.

Sampling and Data Collection

Sampling

Red pine foliage was collected from 50 seedlings per site at the time of planting, from 45 seedlings per site in October of 1984 and from 15 seedlings per site in October of the 1985 through the 1990 field seasons. Seedlings selected are the same seedlings selected for destructive sampling in the leaf water potential and mycorrhizal studies. Measurements associated with these other two studies (basal diameter, height, current height

growth, etc.) are also available for data analysis in this portion of the study. At each collection period all one year old fascicles are removed from the tree. Approximately 100 fascicles are then randomly selected for foliar analysis. The fascicles are then dried at 60^{o} C, ground, and analyzed for concentrations of N, P, K, Ca and Mg.

Data Analysis

Comparisons of differences in foliar nutrient concentrations among sites and years follow the split-plot and time experimental design. Specific differences for a given nutrient are determined through the split-plot analysis of covariance (Table 2.23). Covariates such as soil nutrient content, individual sample tree physiological characteristics, and climatic factors are considered as potential covariates. However, soil nutrient contents were not considered for inclusion as covariates in this years report due to the reanalysis of nutrient concentrations from prior years (refer to element 1). Future work will include soil nutrient variables as possible covariates. Individual covariates are included in the analyses if they increase the sensitivity of the analysis or reduce the variation associated with the independent factors in the analysis while maintaining the statistical assumptions inherent to analysis of covariate procedures.

Table 2.23 Anova table used for analysis of each individual macronutrient concentration

Source of Variation	D.F.	M.S.	F-Test
Covariate	# Group A Cov.[1]	MSC_a	MSC_a/MSE P(S)
Site	2	MSS	MSS/MSE P(S)
Error P(S)	3(2)-# Cov	MSE P(S)	
Covariate	# Group B Cov.	MSC_b	MSC_b/MSE YxP(S)
Years	# Years-1	MSY	MSY/MSE YxP(S)
Site x Years	(2)(Years-1)	MSSY	MSY/MSE YxP(S)
Error YxP(S)	(Years-1)3(2)- #Cov	MSSYxP(S)	

[1] Group A covariates differ by site but not by year

Group B covariates may differ among sites and years

Since growth of red pine is determinate, nutrient concentrations of the one year needles were not acclimated to the individual site conditions by the time of sampling in 1985 (Mroz et al. 1991). Thus only the 1986-1990 samples were included in ELF hypothesis testing. The determinate growth pattern of red pine also dictates that site and tree conditions at the time of bud set and foliage expansion should influence foliar nutrient concentrations. For one year old needles time of leaf expansion and bud set are respectively one and two years prior to the year of foliage sampling. Nutrient concentrations of these samples would also reflect the amount and extent of translocation of nutrients from and to the needle during the year of sampling (R. Van Den Driessche 1984). Thus potential covariates for the analysis should included factors measured two and one years prior to sampling as well as the year during sampling. Work this year has included soil, tree, and climate characteristics from these three years. Future work will include soil nutrient concentrations from these years as well.

Progress

Mean nutrient concentrations and standard deviations of these means are presented in Table 2.24 for each site and year. In general, most nutrient concentrations have been found to be above or near levels reported for adequate growth of red pine. Critical foliar concentration levels have been reported for Mg (0.05%), and Ca (0.12%), while concentrations of N above 1.0% and P above 0.16% have been found to be adequate for growth in plantations (Stone and Leaf, 1967; Hoyle and Mader, 1964; Alban, 1974). Only K concentrations have consistently remained low during the study. K concentrations of .30-.51% have been reported for low to deficient levels for red pine in plantations (Hieberg and Leaf,1961; Madgwick, 1964). Concentrations of N in 1989 were below 1% for the first time during the study. In 1990 nutrient concentrations of N increased above 1.0%. Nutrient concentrations are ranked in the order: N > K > Ca > P > Mg for all years sampled. Standard deviations of individual nutrient concentrations are generally within 10 to 20% of the mean for all sites and years (Table 2.24). The small variation in concentrations reflect the relatively uniform conditions within a site and the lack of genetic variation in red pine.

Analyses to examine site and year differences show year differences for all nutrients and site differences for only Mg (Table 2.25). Foliar concentrations of Mg during the five years of study were significantly ($p \leq 0.05$) higher at the ground site (.0.097%) than at the antenna site (0.092%) but not the control site (0.095%). Concentrations of Ca and Mg increased while concentrations of N decreased from 1986-1990 (Table 2,25, Figures 2.7a, 2.8a, 2.10a). Average foliar concentrations of Ca increased from 0.20% in 1986 to 0.30% in 1990 and Mg increased from 0.086% in 1986 to 0.102% in 1990. Average N concentrations at the sites in 1986 were 1.46% but decreased to as low as 1.02% in 1989. These changes in concentrations are consistent with

Table 2.24. Mean and standard deviation of foliage nutrient concentrations for red pine seedlings at ELF study sites (198-1990)

Site	N%	P%	K%	Ca%	Mg%
1986					
Ground	1.42(.16)	0.13(.01)	0.47(.06)	0.19(.03)	0.08(.01)
Antenna	1.59(.12)	0.14(.02)	0.51(.04)	0.18(.03)	0.08(.01)
Control	1.34(.20)	0.13(.01)	0.49(.06)	0.23(.03)	0.09(.01)
1987					
Ground	1.06(.12)	0.11(.01)	0.34(.07)	0.21(.02)	0.09(.01)
Antenna	1.10(.16)	0.12(.02)	0.33(.04)	0.24(.07)	0.09(.01)
Control	1.04(.15)	0.12(.01)	0.36(.06)	0.23(.03)	0.09(.01)
1988					
Ground	1.16(.14)	0.14(.02)	0.58(.06)	0.25(.05)	0.11(.01)
Antenna	1.27(.15)	0.15(.02)	0.56(.07)	0.22(.04)	0.10(.01)
Control	1.17(.09)	0.13(.01)	0.48(.04)	0.25(.05)	0.09(.01)
1989					
Ground	0.99(.13)	0.14(.03)	0.33(.06)	0.25(.04)	0.11(.01)
Antenna	1.10(.20)	0.13(.01)	0.33(.03)	0.27(.04)	0.10(.01)
Control	0.98(.12)	0.16(.04)	0.33(.03)	0.27(.04)	0.10(.01)
1990					
Ground	1.06(.10)	0.13(.02)	0.38(.03)	0.31(.06)	0.10(.01)
Antenna	1.11(.07)	0.14(.01)	0.38(.04)	0.29(.05)	0.10(.02)
Control	1.20(.07)	0.15(.03)	0.38(.05)	0.31(.06)	0.10(.01)
86-90					
Ground	1.14(.20)	0.13(.02)	0.42(.12)	0.24(.06)	0.10(.02)
Antenna	1.24(.24)	0.14(.02)	0.42(.11)	0.24(.06)	0.09(.01)
Control	1.15(.24)	0.13(.02)	0.41(.08)	0.25(.05)	0.09(.01)

observed nutrient fluctuations with plant maturity (Walworth and Sumner 1987,Lambert 1984, Miller 1981). Concentrations of P and K showed no consistent trends related to tree age.

Site by year interactions were significant for N, P, and K (Table 2.25). Differences in K concentrations among sites were only significant ($p \leq 0.05$) in 1988. However, differences in P among sites were significant during 1986, 1989, and 1990. The changes in K concentrations during the study do not appear to be related to the operation of the ELF antenna (Figure 2.9a). However, levels of P and N in 1990 increased to a greater degree at the control than either the antenna or ground (Figures 2.10a, 2.11a). In 1990 for the first time during the five year period, concentrations of P at the control site were significantly ($p \leq 0.05$) greater than at the ground site (Figure 2.11 a). During 1986-1989 foliar concentrations of N were greater at the antenna than at the control site. However in 1990, N concentrations averaged 1.20% and 1.11% at the control and antenna sites respectively. Although differences in N concentration among sites in 1990 were not significant ($p \leq 0.05$), the increasing trends in N at the control compared to the test sites is similar to the changes in foliar P among the sites during 1990. Foliage collected during 1990 was the first group of foliage sampled which was exposed to relatively high ELF EM fields during bud formation and needle expansion. Thus at this time the reduced concentrations of N and P could be related to the increased levels of EM fields at the test sites.

Detection limits associated with the ANOVA tests were generally below 10% for all nutrients except Ca (Table 2.25). Detection limits were also for the most part lower for site and year factors than year by site interactions. The low detection limits of these analyses are well within the range of acceptability for indicating plant responses to ELF electromagnetic radiation.

Inclusion of covariates into the analysis primarily decreased detection limits associated with the various factors and interactions. The covariates also explained differences in Mg concentrations among sites and annual differences in foliar concentrations of P (Table 2.25). No significant covariates were found for the analysis of Ca concentrations.

Covariate adjusted concentrations generally showed similar site and year trends to those of the unadjusted concentrations (Figures 2.8-2.11). However, differences among sites for a given year were often greater for the adjusted means than the unadjusted means. For example N and K concentration at the control and antenna sites were not significant for the unadjusted means in 1990 (Figures 2.9a, 2.10a). Differences for the adjusted means for these nutrients in 1990 were significant (Figures 2.9b, 2.10b). Future work with the covariates include soil nutrient concentrations. Thus the covariates chosen this year can only be considered as potential covariates for future analyses.

A statistical technique proposed by Bickelhaupt et al. (1979) was used in an effort to normalize the foliar nutrient concentrations for annual variations in air temperature and

Table 2.25. Results of red pine foliage nutrient analyses of variance (p value) and computed detection limits (%) with and without covariates (1986-1990)

	P Value				
	Ca	Mg	K	N	P
Without Covariates					
Site	.258	.032	.422	.059	.074
Year	.000	.000	.000	.000	.000
Year x Site	.570	.084	.001	.009	.036
	%				
Without Covariates					
Site	8.7	3.4	6.6	7.5	5.3
Year	11.2	6.2	1.8	4.8	5.4
Year x Site	19.4	10.8	8.7	8.2	9.4

	P Value				
	Ca[1]	Mg[1]	K[2]	N[3]	P[4]
With Covariates					
Site		.215	.758	.133	.122
Year		.000	.000	.000	.227
Year x Site		.102	.000	.002	.036
	%				
With Covariates					
Site		3.6	7.5	5.8	6.0
Year		5.4	4.5	4.4	5.0
Year x Site		9.4	7.8	7.6	8.7

[1]Covariate=Average soil temp. (10cm) year of sampling, average soil temp. (10cm) June year prior to sampling

[2]Covariate=Soil moisture content (10cm) June year of sampling

[3]Covariate=Mycorrhizal tips per gram of root

[4]Covariate=Soil water potential (5cm) September year of sampling

Figure 2.11a

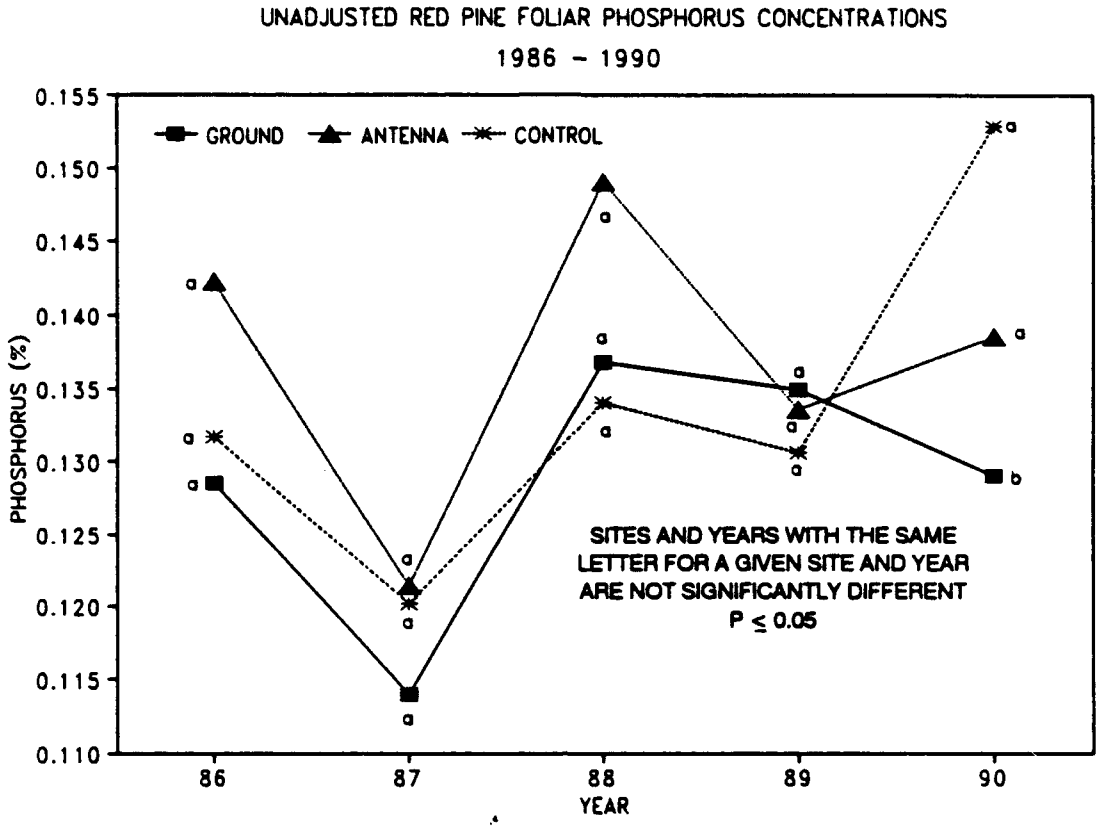


Figure 2.11b

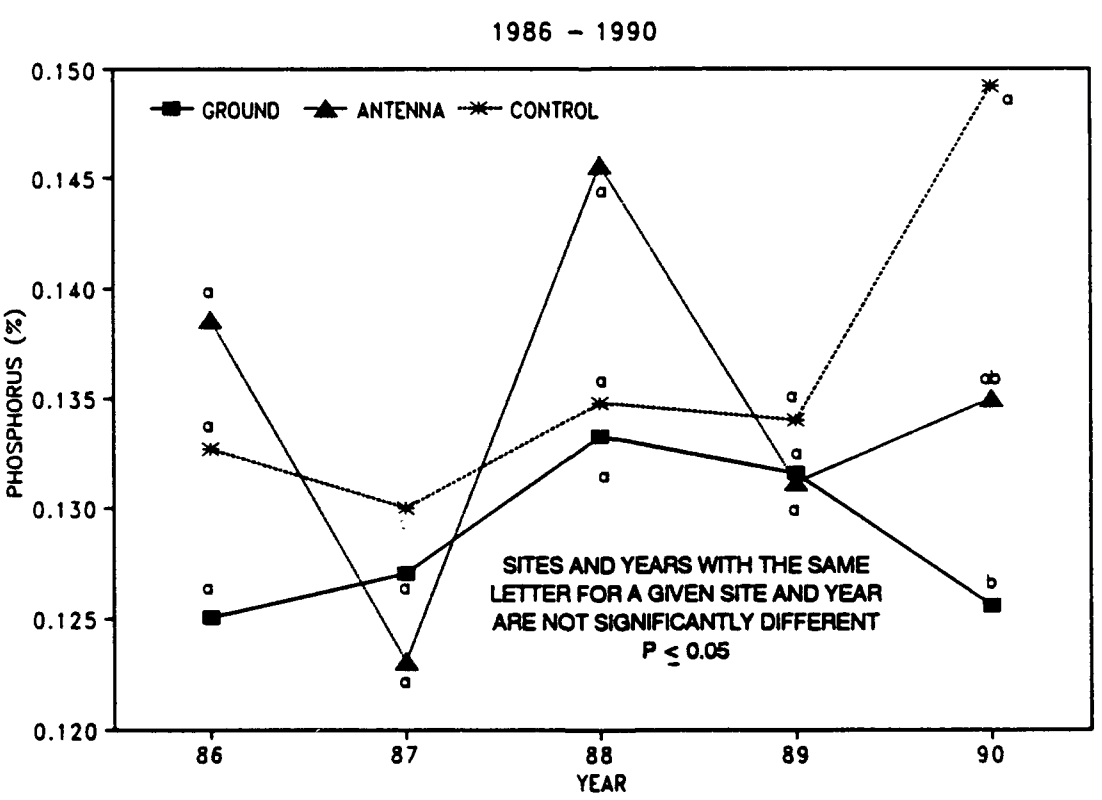


Figure 2.7a

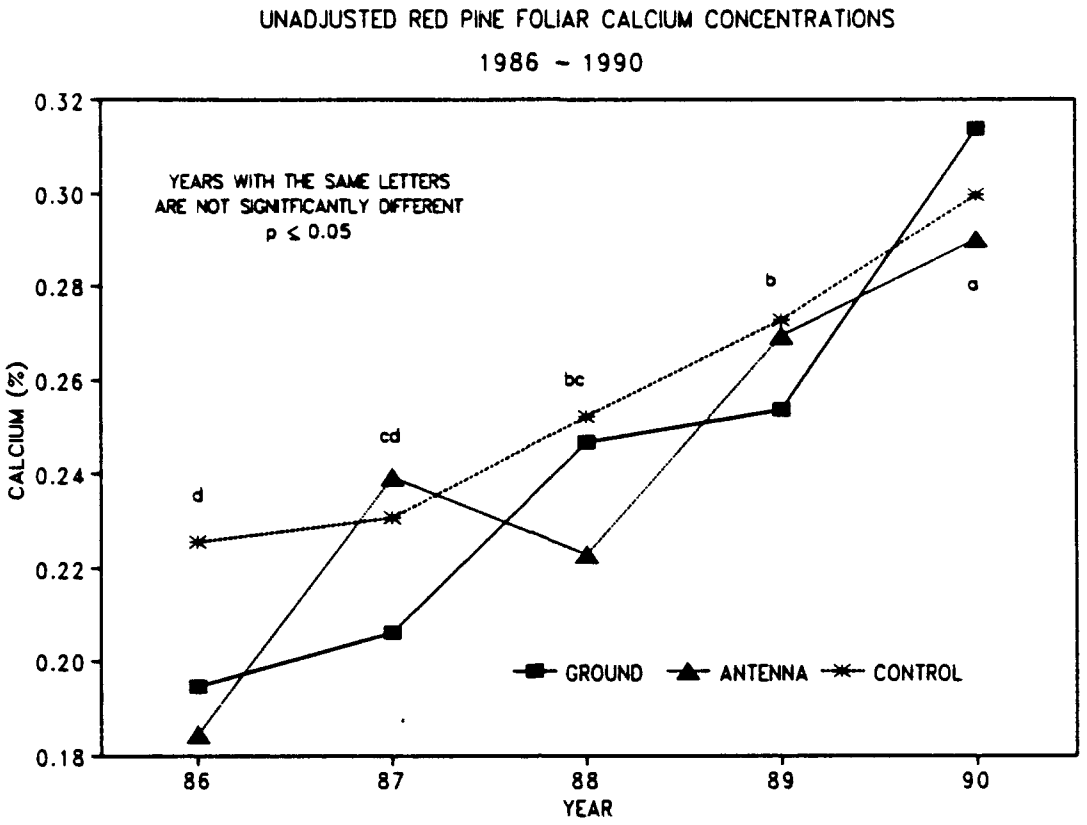

UNADJUSTED RED PINE FOLIAR CALCIUM CONCENTRATIONS
1986 - 1990
YEARS WITH THE SAME LETTERS
ARE NOT SIGNITFICANTLY DIFFERENT
p ≤ 0.05
CALCIUM (%)
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
d
cd
bc
b
a
GROUND
ANTENNA
CONTROL
86
87
88
89
90
YEAR

Figure 2.8a

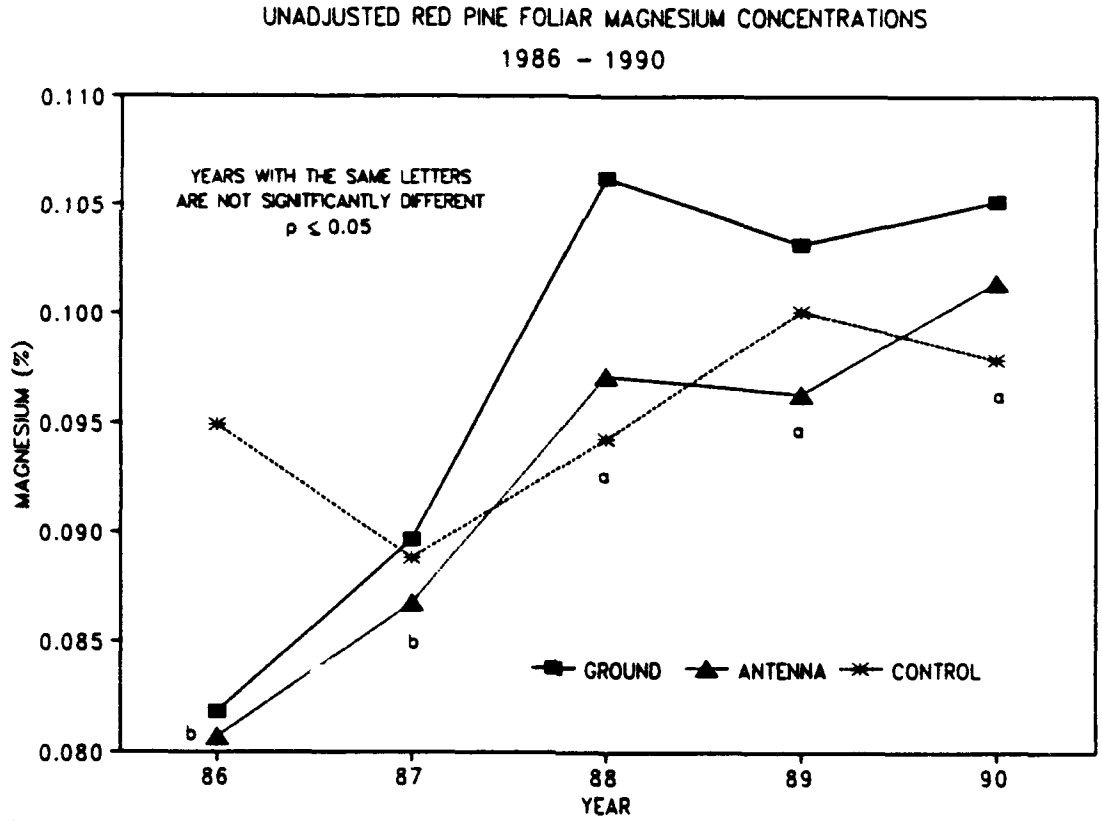


Figure 2.8b

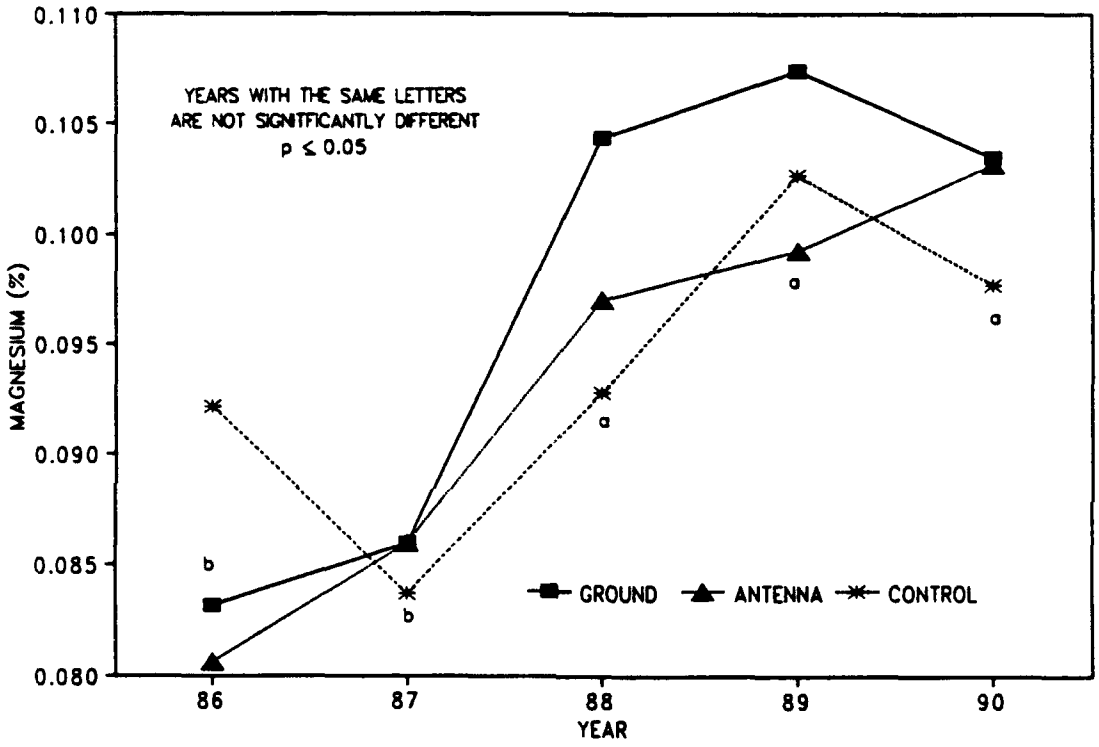


Figure 2.9a

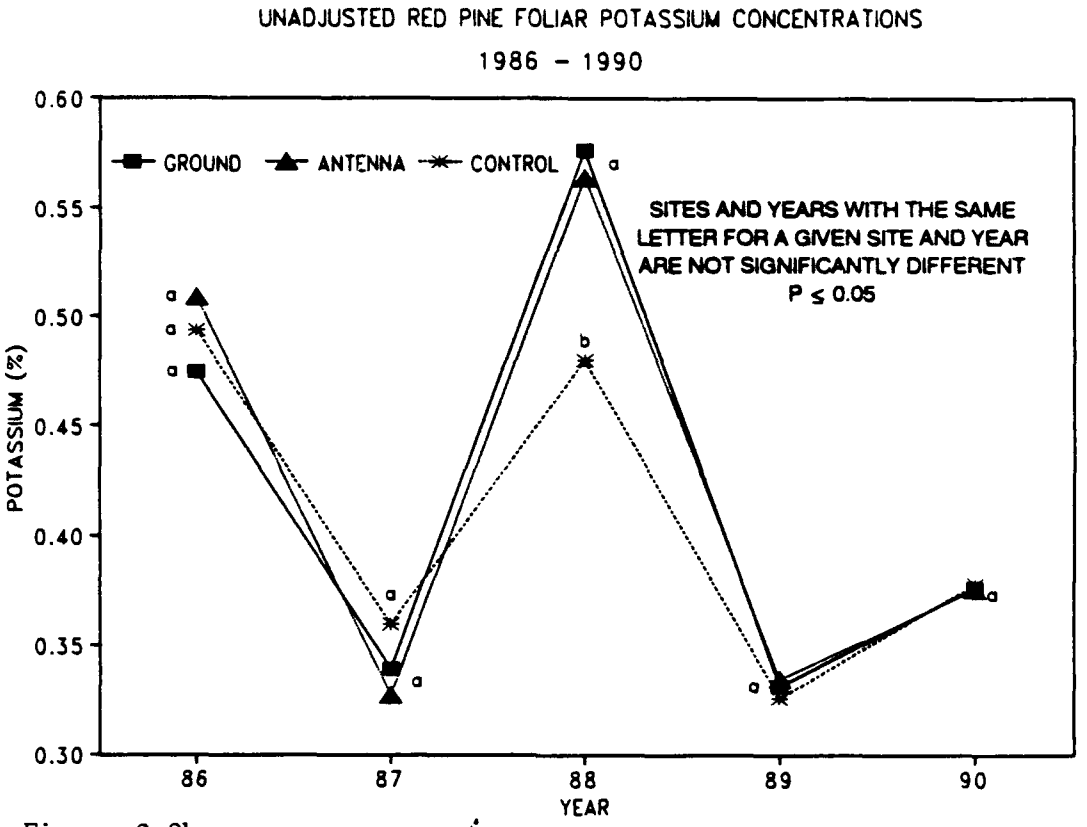


Figure 2.9b

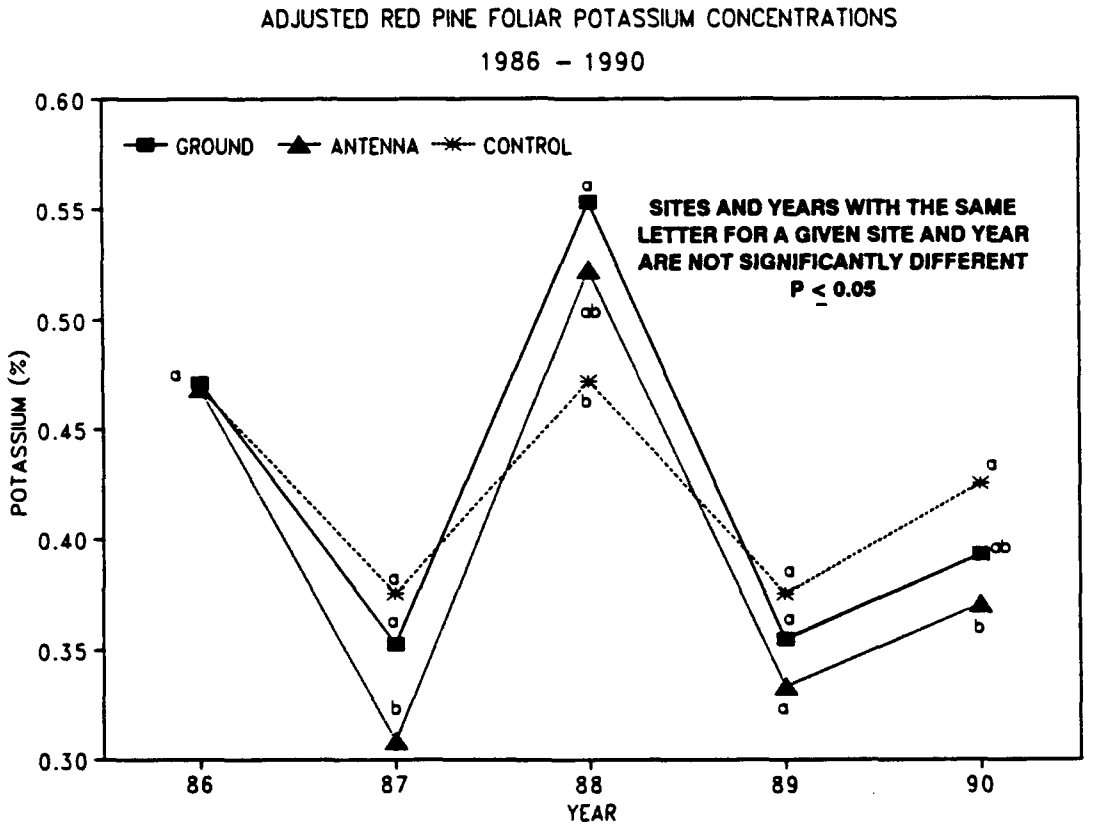


Figure 2.10a

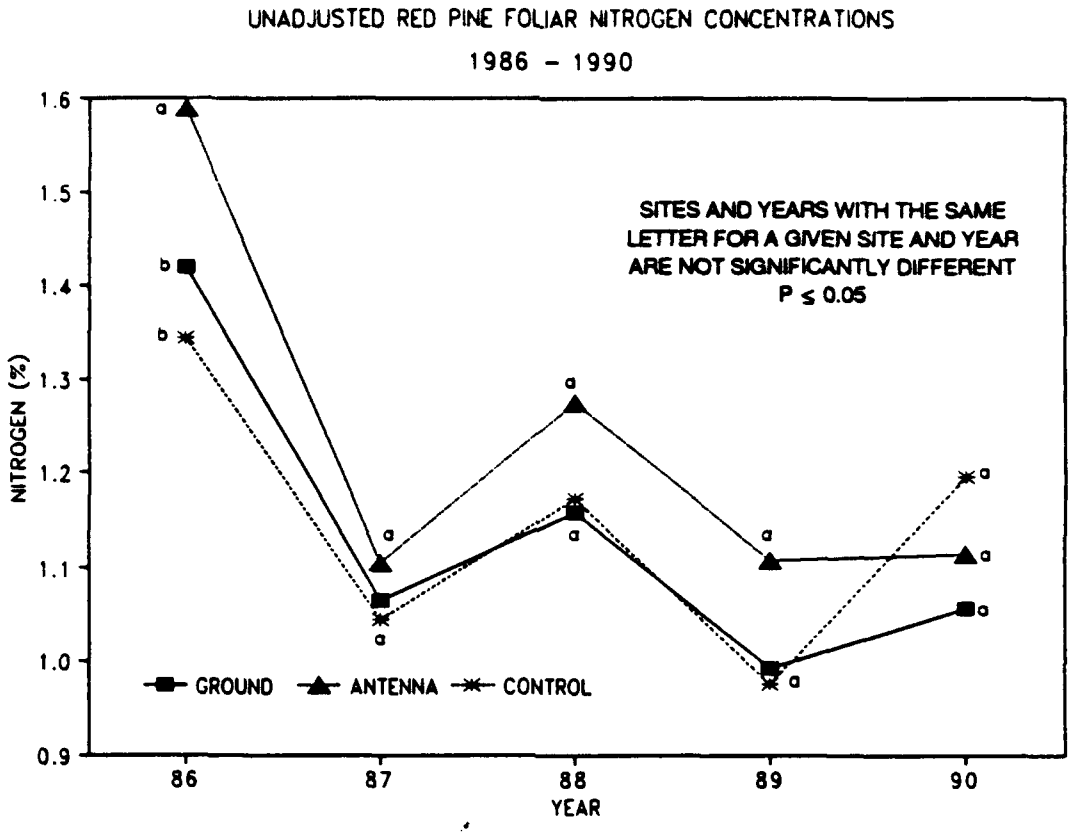
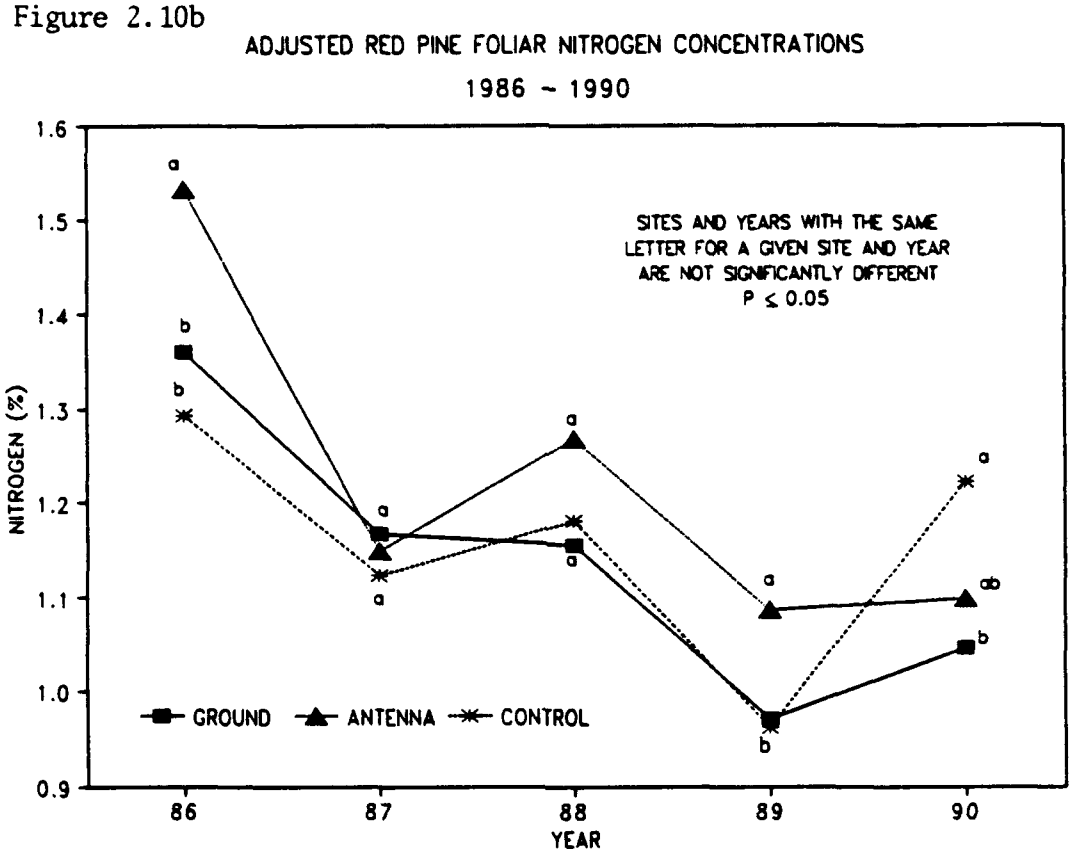


Figure 2.10b



precipitation. The first step in this procedure is to fit a regression equation using annual deviations in precipitation and air temperatures as independent variables and the annual variations in foliar concentrations as the dependent variables. Coefficients were determined for the independent variables for each nutrient separately. The coefficients of determination (r^2) for these equations were all below 0.15. The corresponding fit of these equations were so poor that it was felt that normalizing the nutrient concentrations using the methods outlined by Bickelhaupt et al. (1979) would serve little purpose. A number of differences existed between the stands in which this procedure was initially developed by Bickelhaupt et al. (1979) and the plantations at the study sites. First the plantations used by Bickelhaupt were mature (20-40 years old) while the trees at the control and test sites were 9 years old (nursery and field age) in 1990. Also only current year foliage was used by Bickelhaupt et al. (1979). Thus this procedure may have limited use for this study.

Summary

The observed decreases in foliar concentrations of N and P in 1990 at the ground and antenna sites compared the control site would be consistent with a hypothesized alteration of foliar chemistry by ELF antenna operation. However, at this time there is no supporting evidence linking field exposures to these alterations in foliar nutrients. Future work will evaluate whether measured EM field strengths are correlated to foliar nutrient concentrations, if these changes in concentrations of N and P persist, and evaluate whether soil concentrations are important covariate for red pine nutrient statistical analyses.

ELEMENT 3: PHENOPHASE DESCRIPTION AND DOCUMENTATION

Phenological events, or the timing of certain morphological processes, are important phytometers of plants under stress. Events, such as timing of stem elongation, bud break, leaf expansion, flowering, fruiting and leaf senescence have been used in the past to monitor and assess a plant's response to factors such as climate and soils. Morphological characteristics, such as leaf area, stem length, number of buds, number of leaves, number of flowers, and number of fruit have also been used to monitor a plant's response to these factors. By combining both phenological and morphological information, a better understanding of the potential changes plants will manifest in response to "major" perturbations.

Starflower, *Trientalis borealis* Raf., is an important herbaceous species in many northern ecosystems. It is especially important in the hardwood ecosystems of the north central region. Phenophases of starflower have been well documented by Anderson and Loucks (1973) in northern Wisconsin by Helenurm and Barrett (1987) in Canada. Because there is some information on the phenophases of starflower and on its morphological characteristics and because we consider starflower to be a sensitive species to stand disturbances, we have chosen it to be an indicator of ecosystem responses to extremely low frequency (ELF) fields. It is a major herbaceous species on both the control site and the ELF antenna site.

To assess the effects of ELF fields on *Trientalis borealis*, the objectives of this element are to: 1) describe and document specific changes in phenological events and in the morphological characteristics of *Trientalis borealis* prior to and during operational use of the ELF antenna and 2) use these data to test hypotheses of possible changes in physiological and phenological processes due to ELF fields.

> The main scientific hypothesis to be tested each year is there is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* between the antenna and the control sites within a year.
>
> The hypothesis to be tested over all years is there is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* before and after the ELF antenna becomes operational.

Morphological characteristics (number of buds, number of flowers, number of fruit, and leaf senescence) will also be analyzed within the context of these hypotheses. Ambient characteristics, described in Element 1, within each year will

be used as covariates to explain significant differences in phenological characteristics of leaf expansion, leaf size (area, length, and width), and stem length between sites, and among years and site by year interactions.

Sampling and Data Collection

During the 1991 field season, data were collected at the antenna and control sites between April 29 and August 22. Each site was sampled twice a week from April 29 until June 22 to delineate flowering periods and leaf expansion with greater precision. After full leaf expansion and flower development, each site was sampled once a week until August 22. Parameters measured per plant for each observation period included stem length, length and width of the largest leaf, number of leaves, number of buds, number of flowers, number of fruit, number of yellow leaves (leaves senescing), and number of brown leaves. To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained for each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 m^2 subplots. Individual plants within each subplot were then numbered and tagged until a normal distribution of mean stem length was attained. Stem length was used as the response variable for this determination because it is a prime indicator of a herbaceous plant's potential sexual productivity. A normal distribution of stem length insures an adequate representation of the population for analysis of variance techniques. The number of meter square subplots required to obtain a minimum sample size of 200 plants varied between the antenna and control site and among weeks sampled. To reduce bias in choosing the 200th individual, all individual plants were tagged and measured in the subplot where the 200th plant occurred, hence sample size was unequal across sampling days. This sampling method was maintained for each individual plant until tagged individuals began to die or were eaten. Thereafter, observations were taken only on the remaining tagged individuals. Maximum leaf area was estimated for each plant by 1) taking the largest leaves on 15 randomly sampled plants off the herbaceous reserves at each observation period in 1986, 1987, 1988, 1989, 1990, and 1991 2) measuring leaf length, leaf width and leaf area on these 15 samples, and 3) developing regression equations for leaf area (dependent variable) using leaf length and width as independent variables.

Progress

Phenological characteristics

In 1991, stem and leaf expansion on the antenna site began at the same time. Bud formation on the control site began 7 days earlier than on the antenna site (April 29)

(Figure 3.1G). Flowering on the control site also began 4 days earlier (May 13) than flowering on the antenna site (May 17) (Figure 3.2G). As with flower formation, fruiting occurred 4 days earlier (May 22) on the control site than on the antenna site (May 26) (Figures 3.3M and 3.3N). Leaf senescence (yellowing leaves) began earlier on the control site (June 3) compared with the antenna site (June 7) (Figures 3.4M and 3.4N) while the occurrence of dead leaves (brown leaves) began at the same time (June 7) on both sites (Figures 3.5M and 3.5N). Similar relationships occurred in the 1990, 1989, 1988, 1987, 1986, or 1985 growing seasons indicating that the ELF fields present during the 1991 growing season had no distinguishable effect on the timing of starflower's phenological events.

During the 1985-1989 growing seasons, flowering and fruiting on both sites began when the previous event was at its maximum except for flowering on the antenna site (Figure 3.6A-3.6J). However in 1990 (after the antenna became fully operational - September,1989), flowering and fruiting on the antenna site seemed to be quite different from previous years and from the control site (Figures 3.6K and 3.6L). The initiation of flowers and fruits began before the peak in number of plants with buds and number of plants with flowers. The proportion of plants flowering was significantly lower on the control site (<12%) than in years 1989, 1988, 1987, 1986, and 1985 (>20%) indicating that there is some phenological and morphological change occurring on this site. This change may be due to climate, handling, or to interactions among these factors. Significant differences in the number of plants flowering were not detected in 1990. In 1991, timing of flowering and fruiting on the antenna site was similar to patterns in 1989, 1988, 1987, 1986, and 1985. The proportion of plants with buds, flowers, and fruit was similar between the antenna and the control site (Figures 3.6M and 3.6N). Reasons for the changes observed in 1990 are unclear. Optimum climatic conditions in 1991 (higher temperatures and precipitation amounts - Element 1) may be the reasons for similar patterns in 1991. At this time, differences in the relationships of phenological events between the antenna and control sites cannot be discerned except in the proportion of plants flowering and the time at which flowering and fruiting begins relative to the time of peak numbers of plants with buds and flowers in 1990. These differences were not evident in 1991.

Analysis of covariance (ANCOVA) was used to determine if climatic and microsite characteristics could be used to explain differences in stem expansion (cm/time period), leaf expansion (cm/time period), and leaf area expansion (cm^2/time period) between sites (antenna vs control), years, and site by years (Table 3.2). The same ANCOVA was used in 1991 as in 1990, 1989, 1988, and 1987. Error terms (1 and 2) for this year included sampling period (P) as in 1990, 1989, and 1988.

Figure 3.1: Relative frequency for number of plants with one or more buds by sampling date on the control and the antenna sites for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), 1990 (F), and 1991 (G).

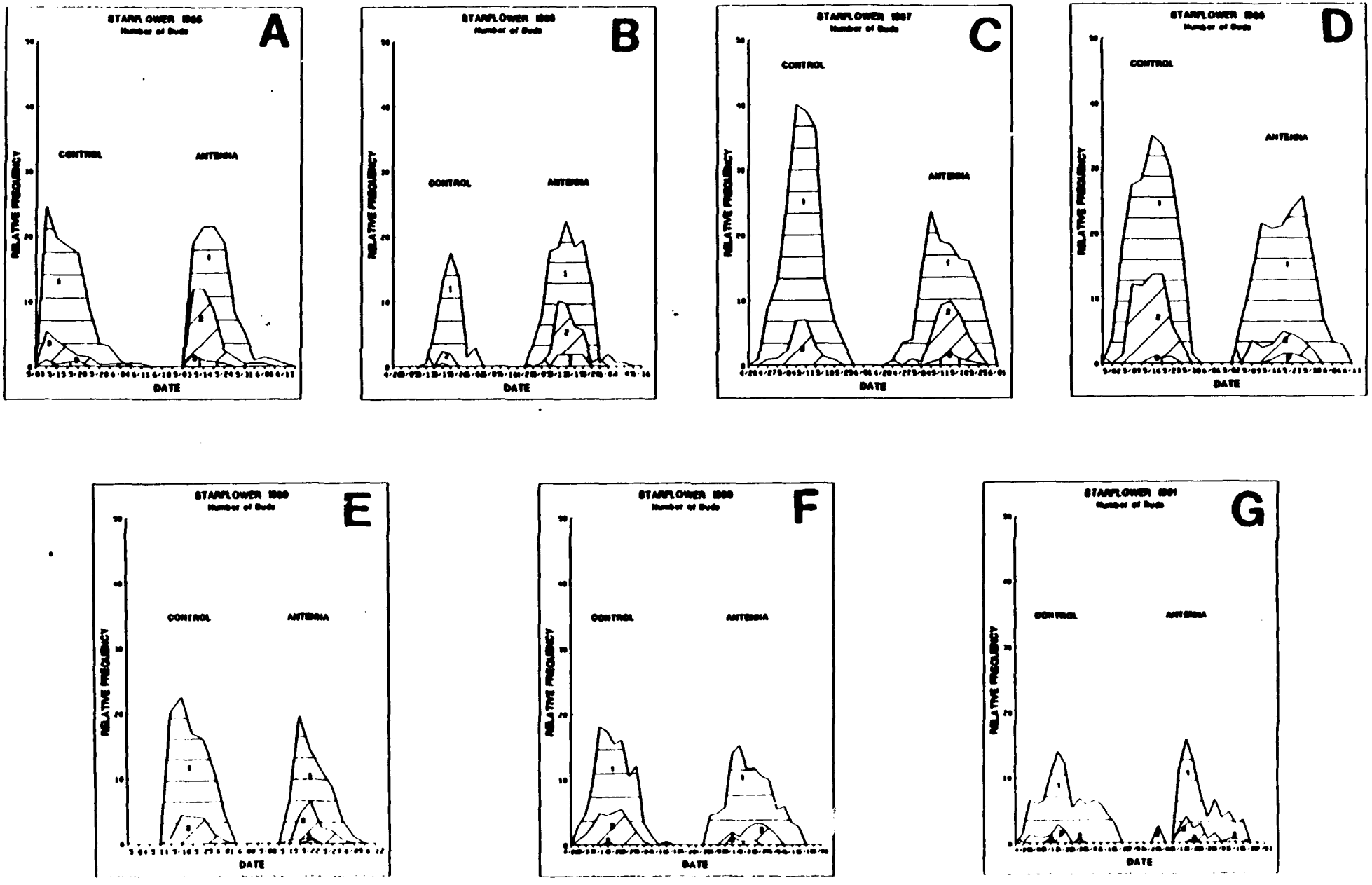


Figure 3.2: Relative frequency for number of plants with one or more flowers by sampling date on the antenna site and the control site for 1985 (A), 1986 (B), 1987 (C), 1988 (D), 1989 (E), 1990 (F), and 1991 (G).

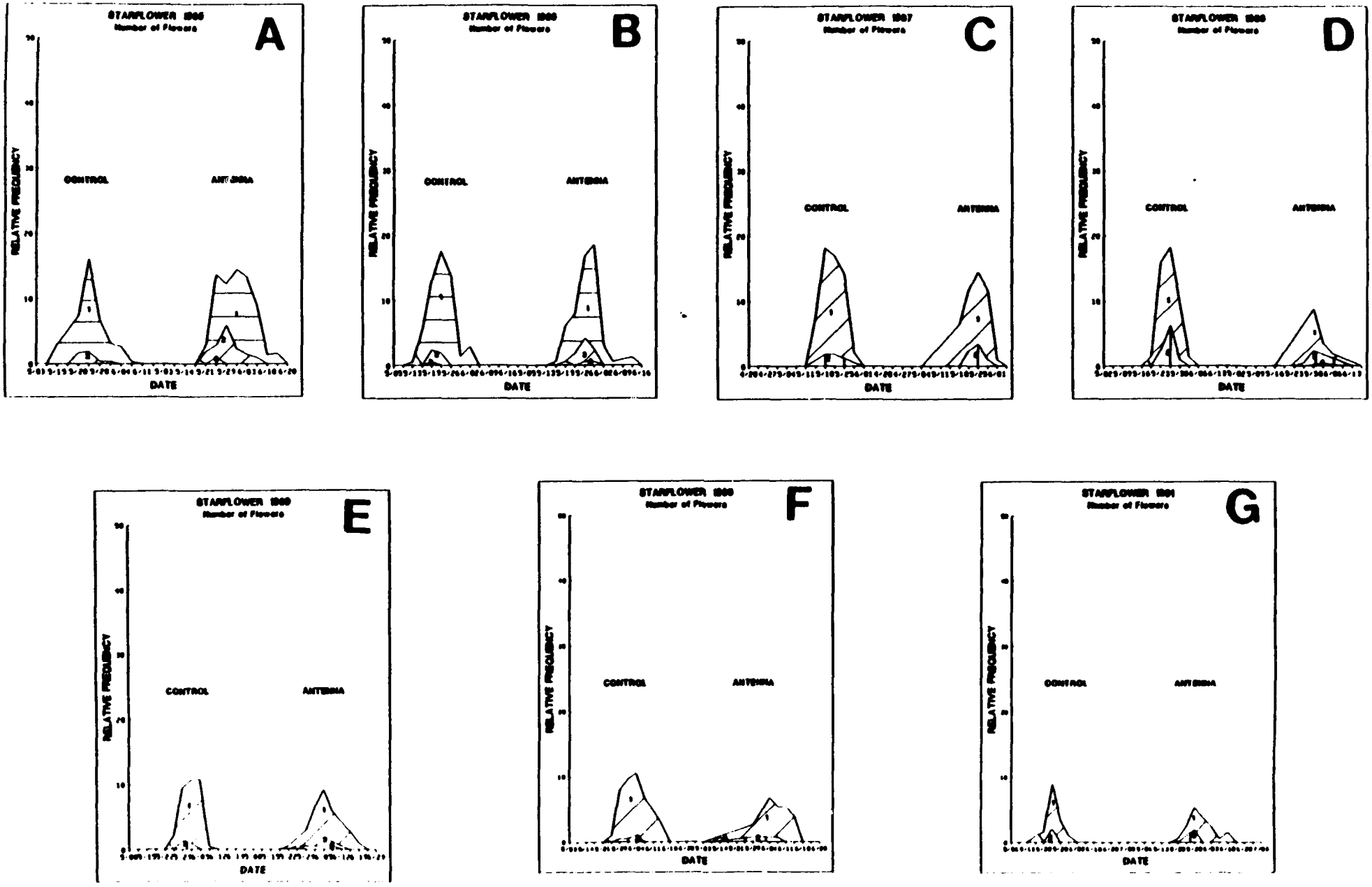
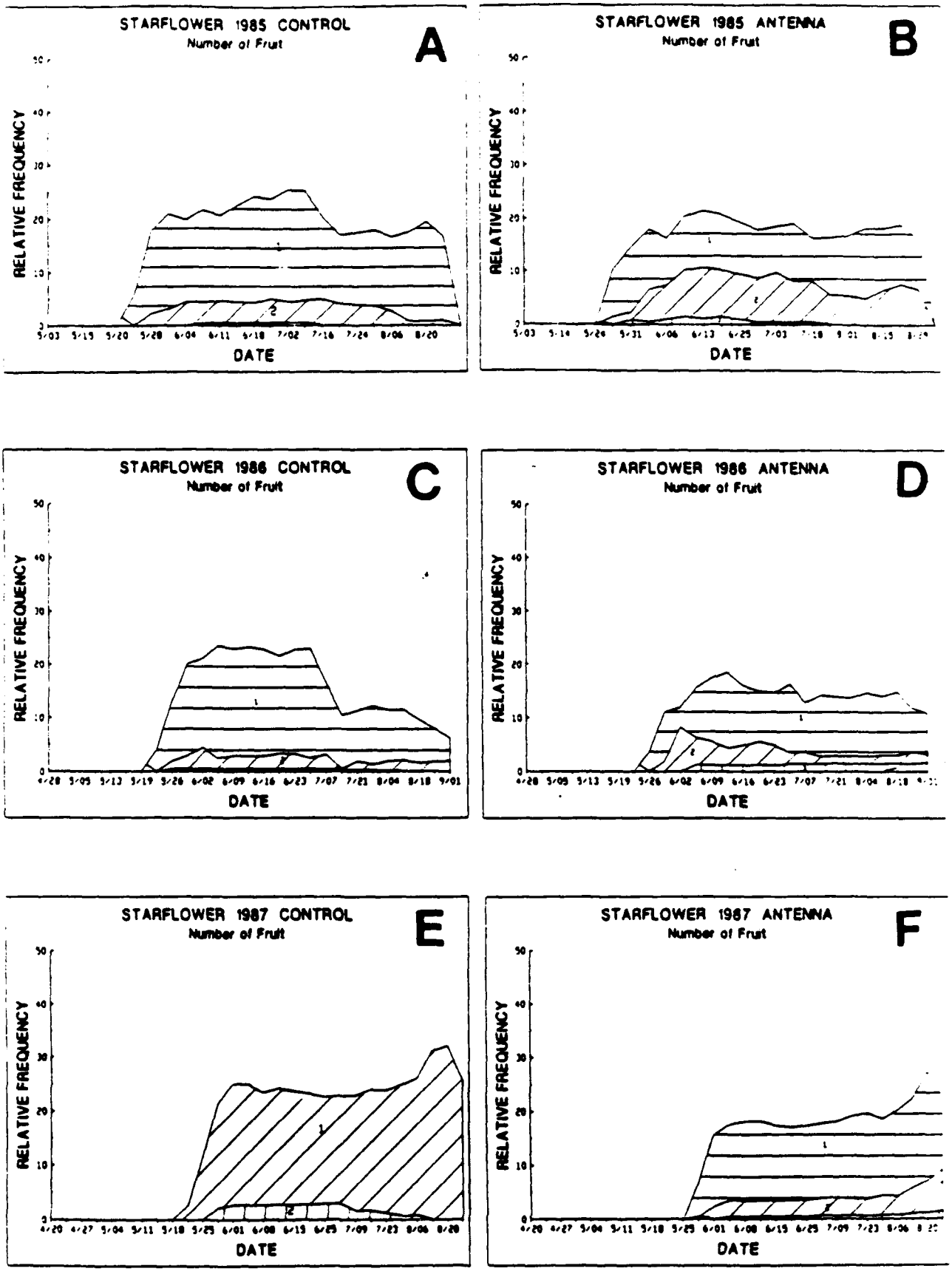
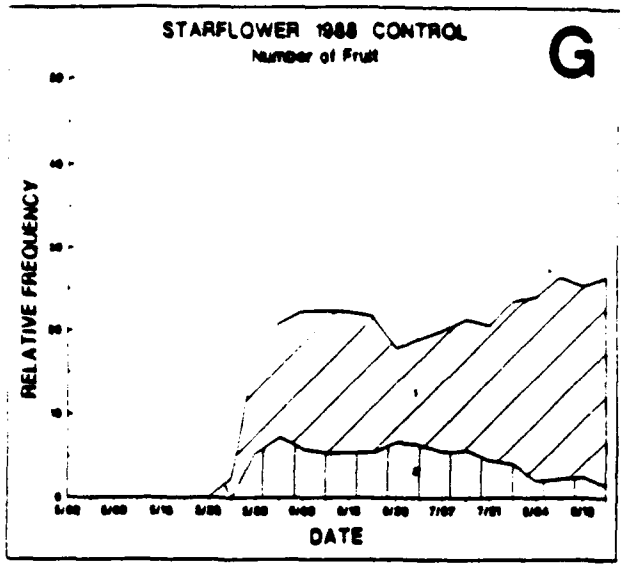
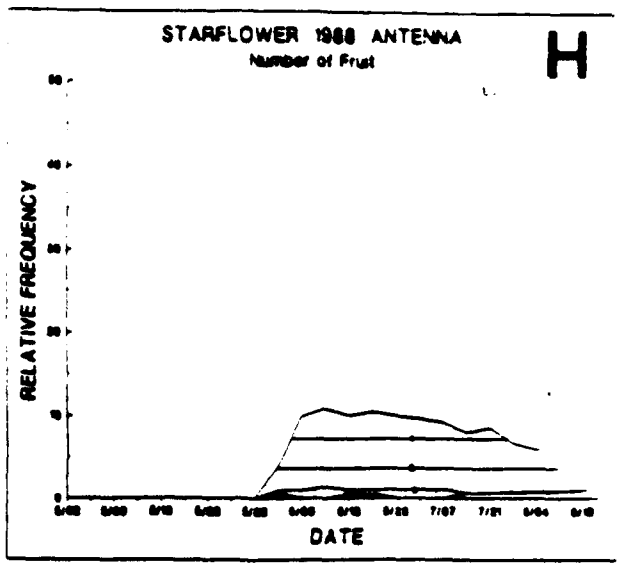
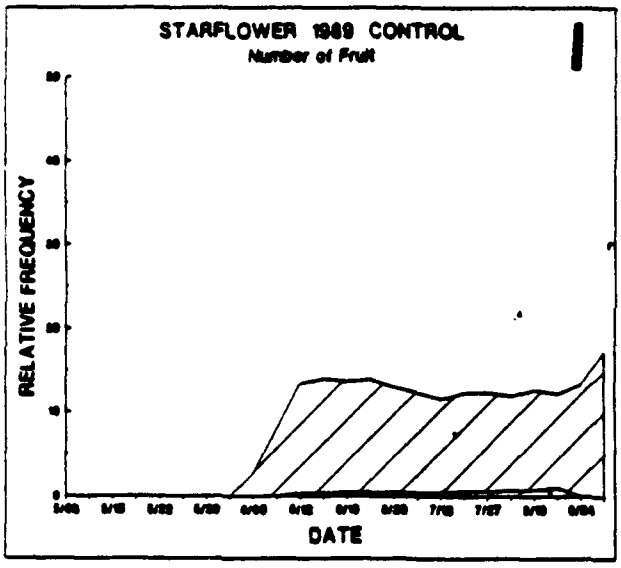


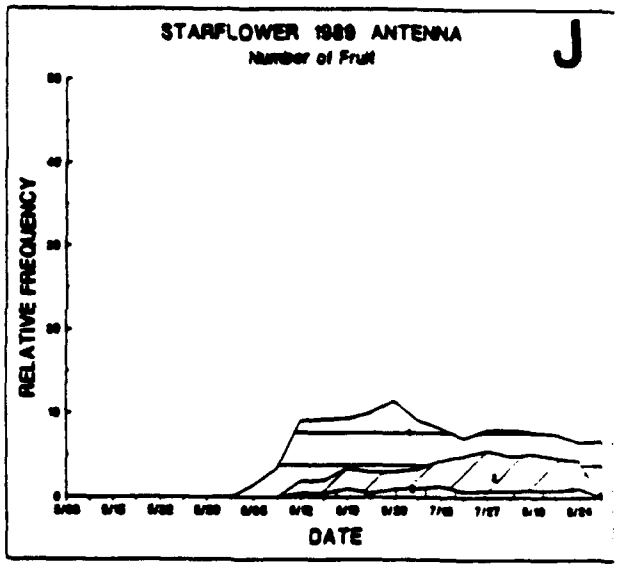
Figure 3.3: Relative frequency for number of plants with one or more fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), and 1991 (M); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), and 1991 (N).

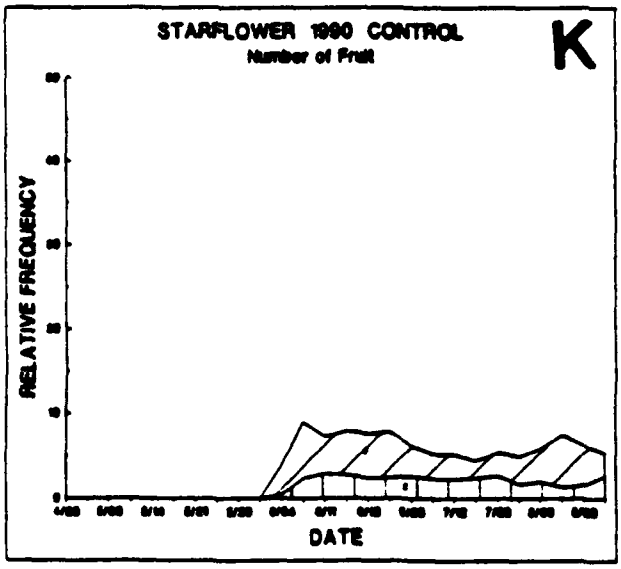


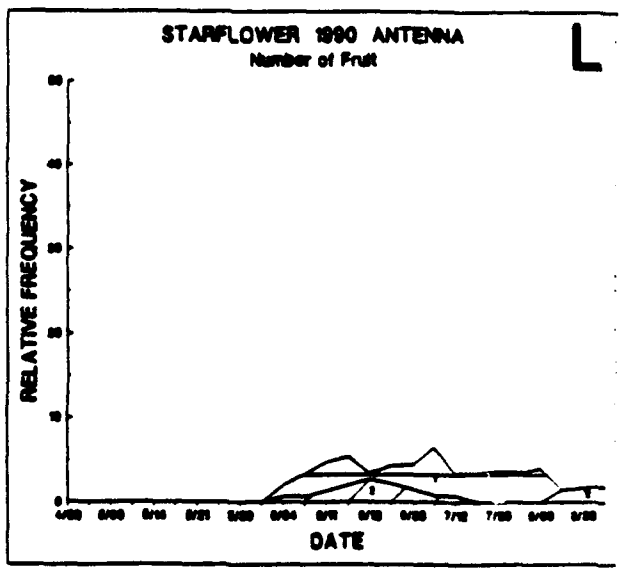

STARFLOWER 1988 CONTROL
Number of Fruit
G
RELATIVE FREQUENCY
DATE

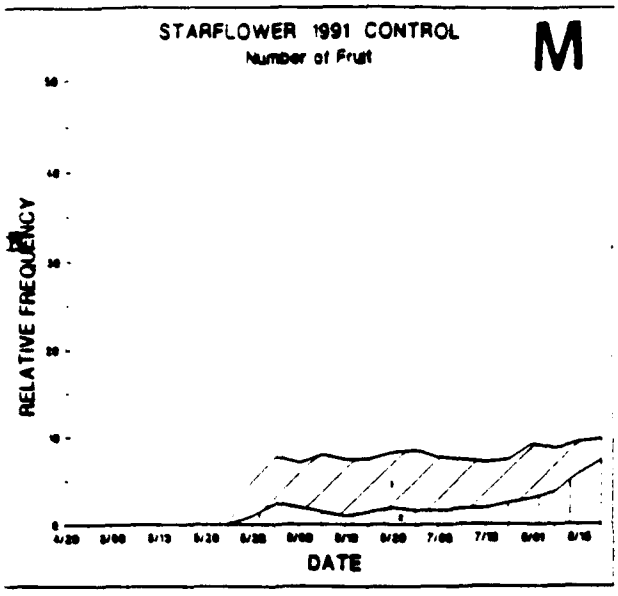

STARFLOWER 1988 ANTENNA
Number of Fruit
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
Number of Fruit
I
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 ANTENNA
Number of Fruit
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
Number of Fruit
K
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 ANTENNA
Number of Fruit
L
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 CONTROL
Number of Fruit
M
RELATIVE FREQUENCY
DATE

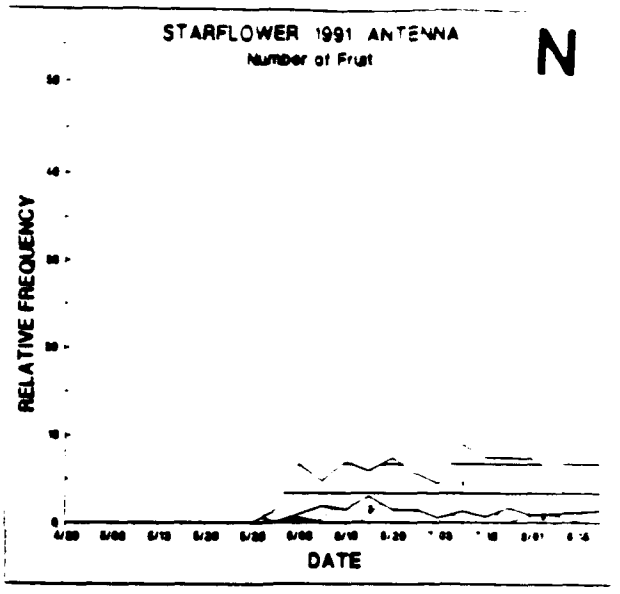
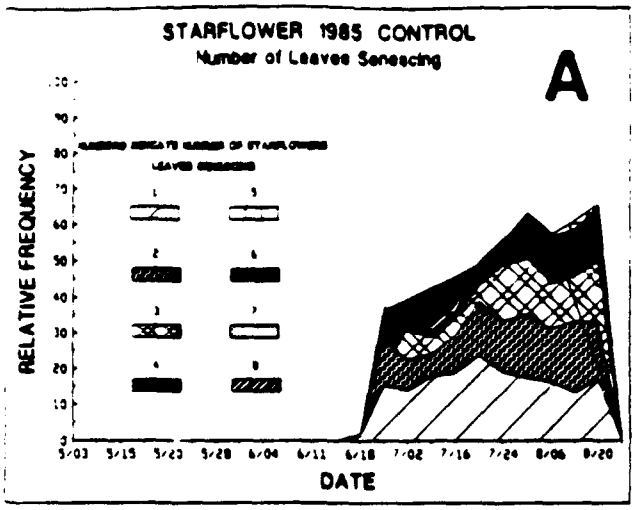
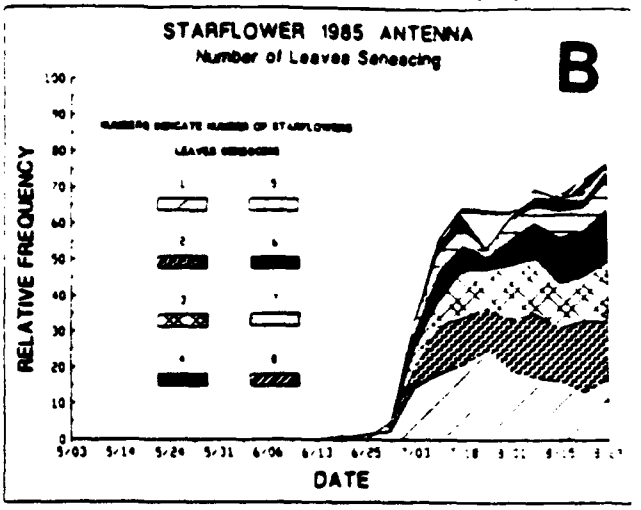
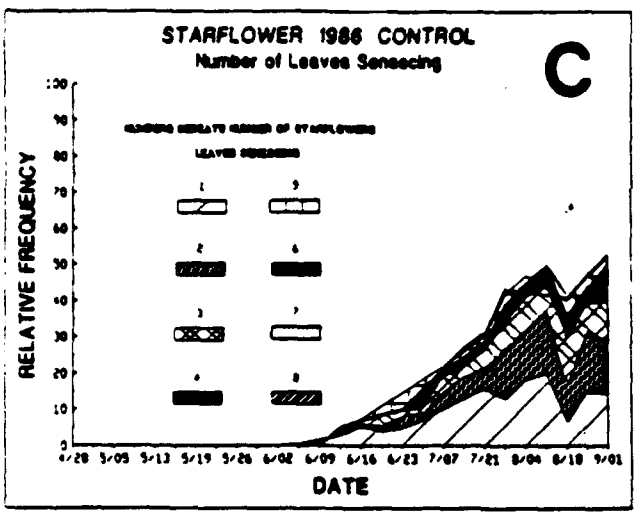
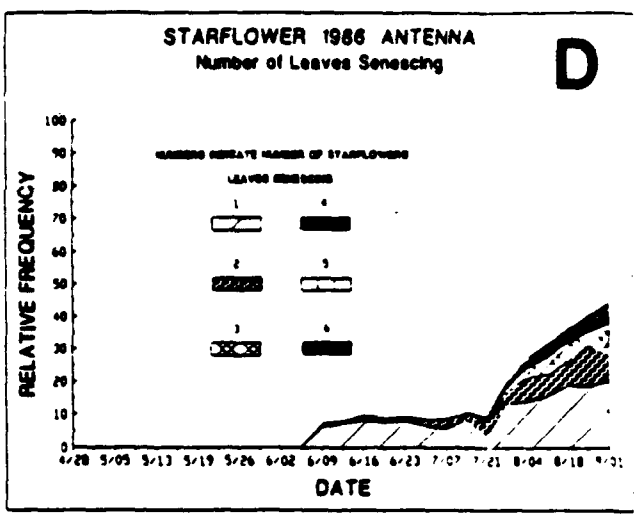

STARFLOWER 1991 ANTENNA
Number of Fruit
N
RELATIVE FREQUENCY
DATE

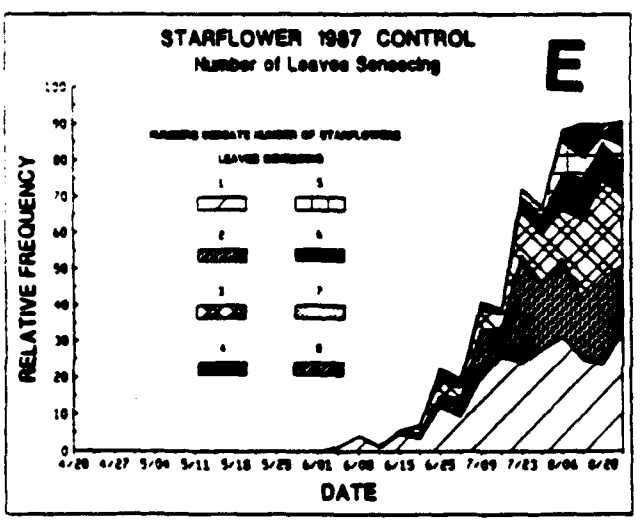
Figure 3.4: Relative frequency for number of plants with one or more leaves senescing by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), and 1991 (M); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), and 1991 (N).

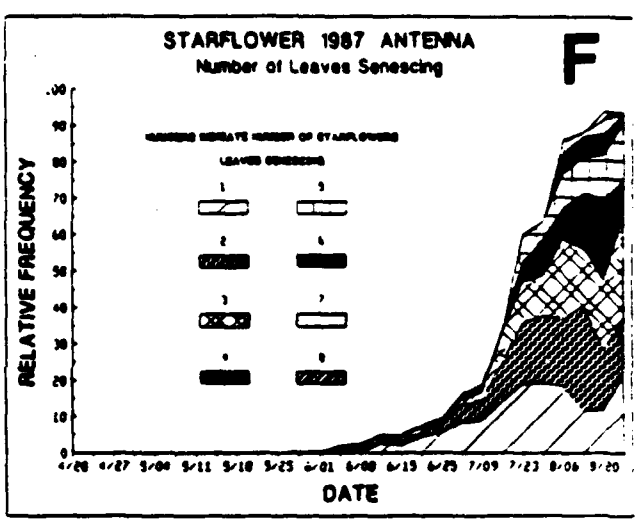


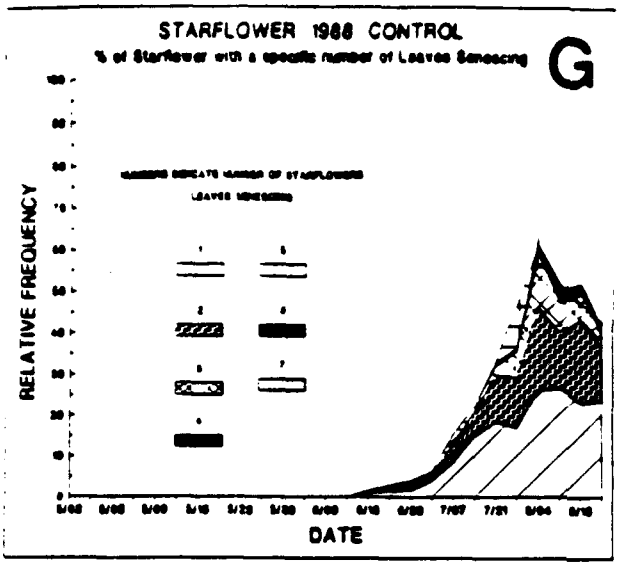


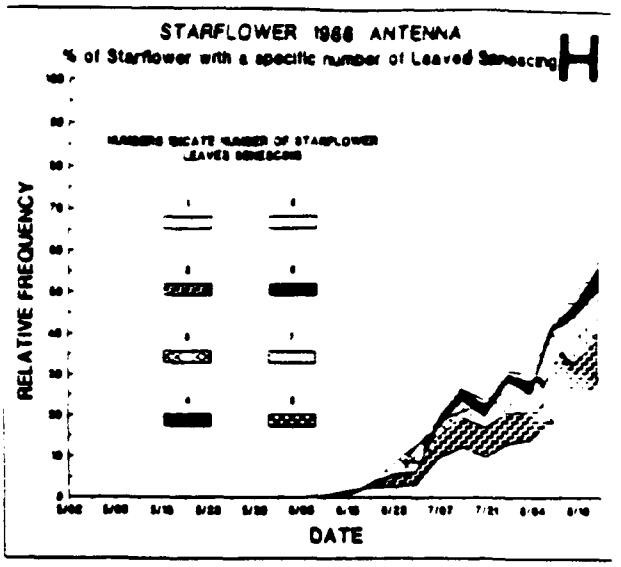


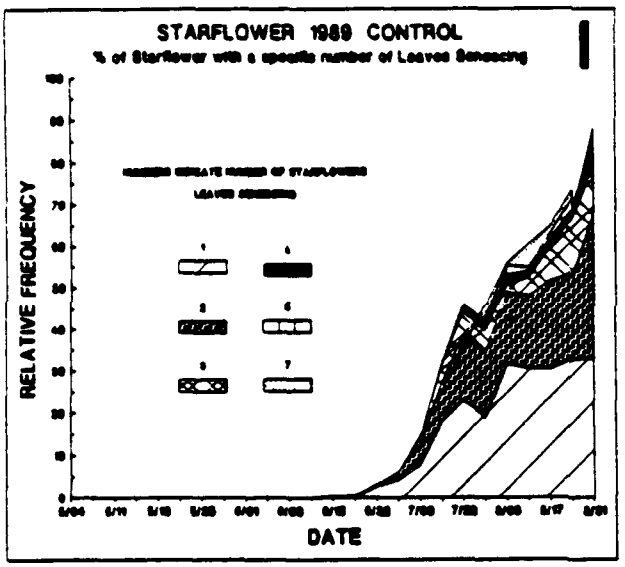


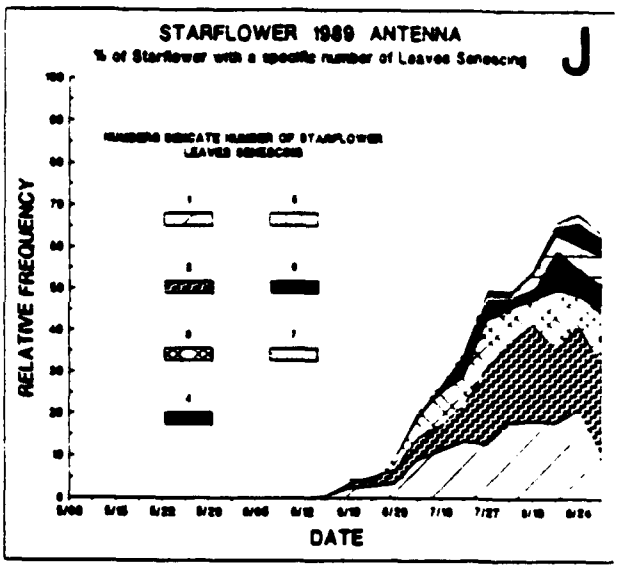


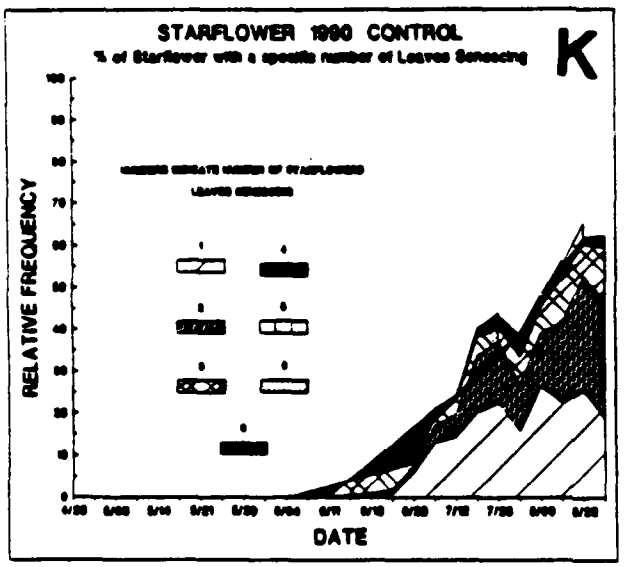


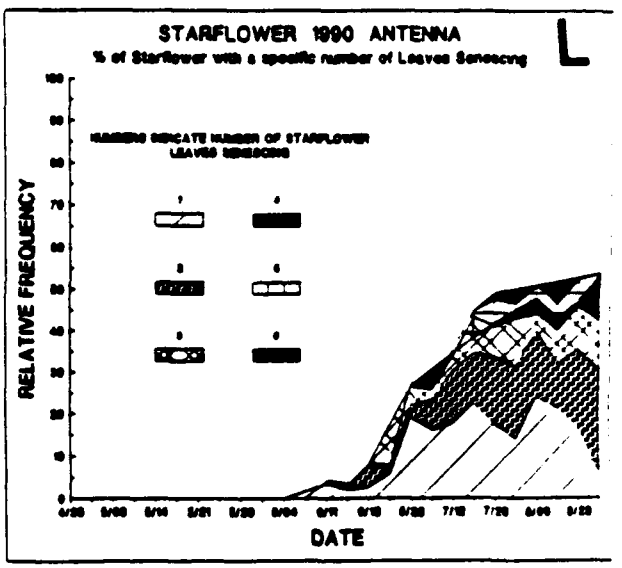

STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Leaves Senescing
G
RELATIVE FREQUENCY
DATE

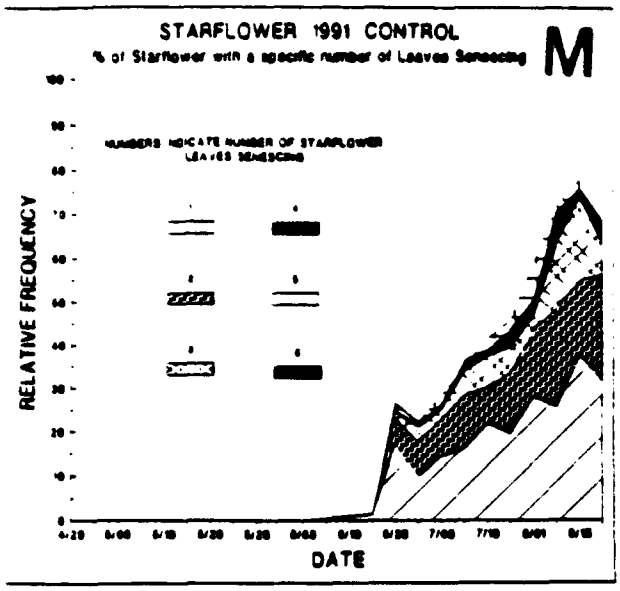

STARFLOWER 1988 ANTENNA
% of Starflower with a specific number of Leaves Senescing
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Leaves Senescing
I
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Leaves Senescing
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
% of Starflower with a specific number of Leaves Senescing
K
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 ANTENNA
% of Starflower with a specific number of Leaves Senescing
L
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 CONTROL
M
RELATIVE FREQUENCY
DATE

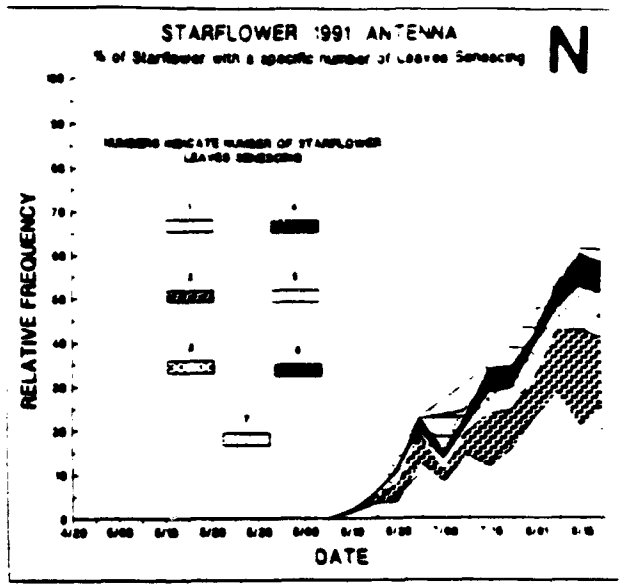
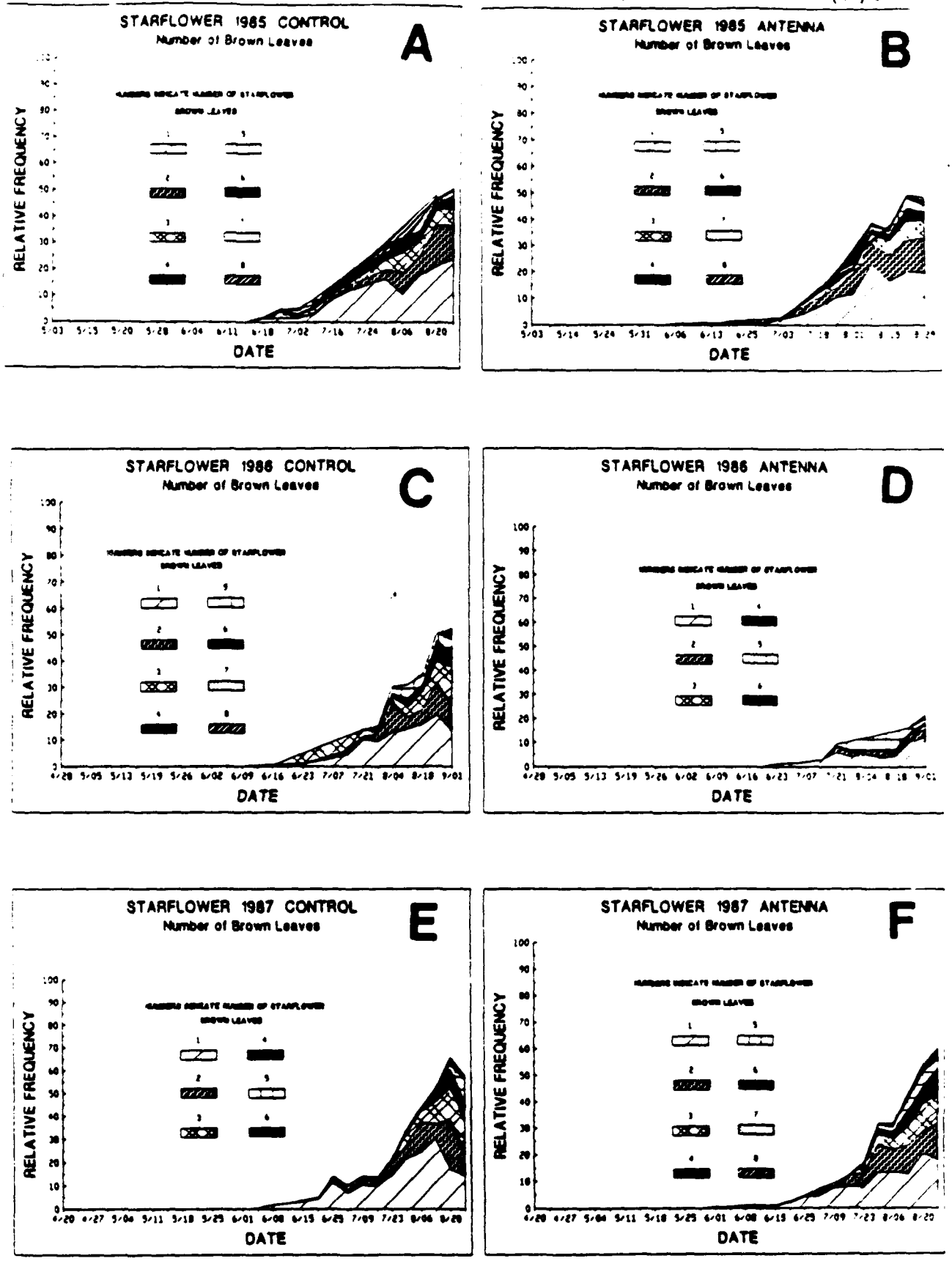
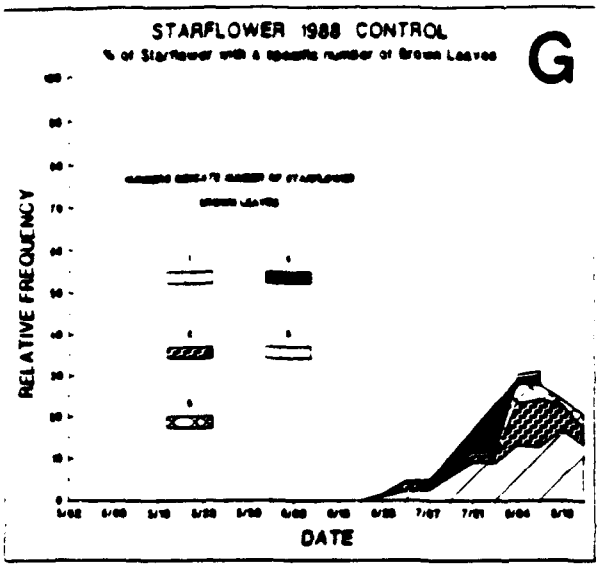
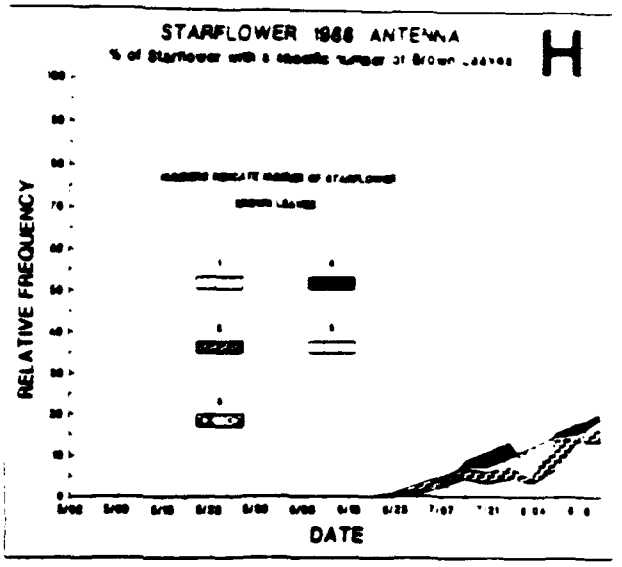
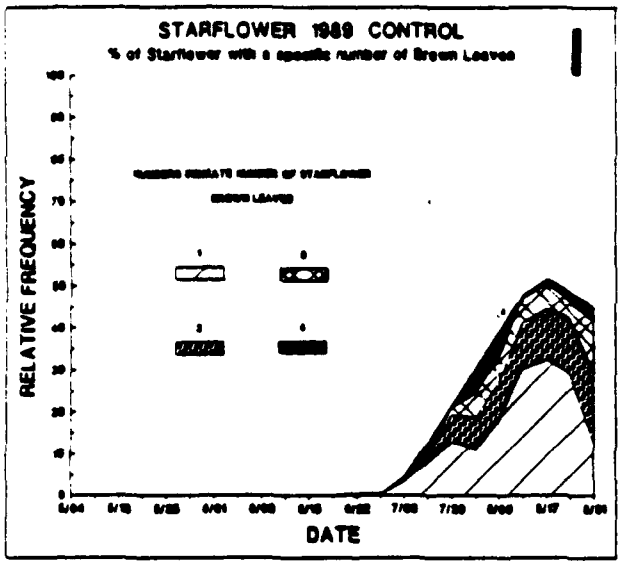

STARFLOWER 1991 ANTENNA
N
RELATIVE FREQUENCY
DATE

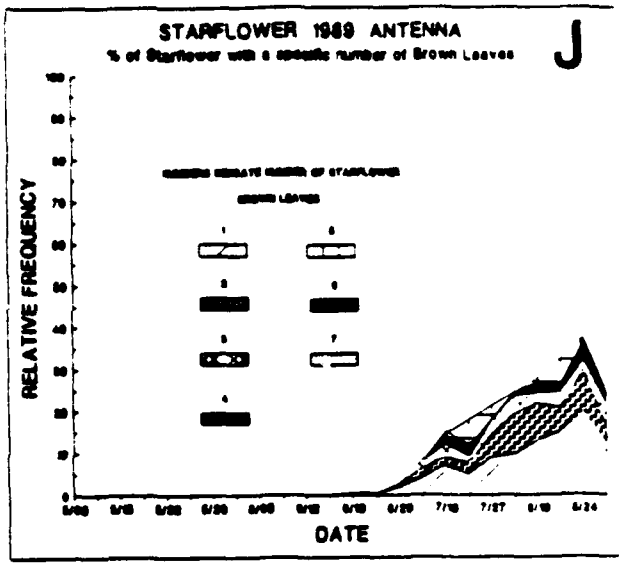
Figure 3.5: Relative frequency for number of plants with one or more brown leaves by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), and 1991 (M); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), and 1991 (N).

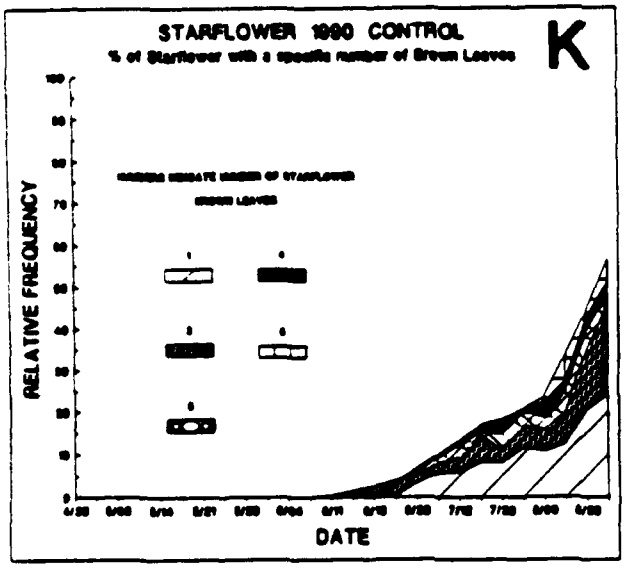


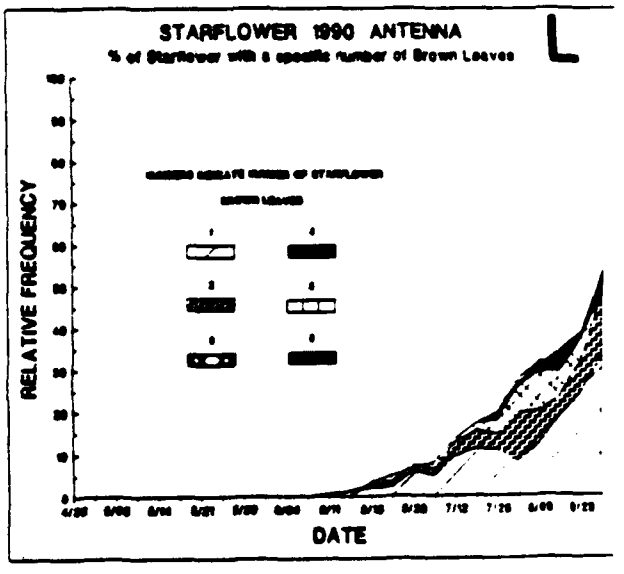

STARFLOWER 1988 CONTROL
% of Starflower with a specific number of Brown Leaves
G
RELATIVE FREQUENCY
DATE

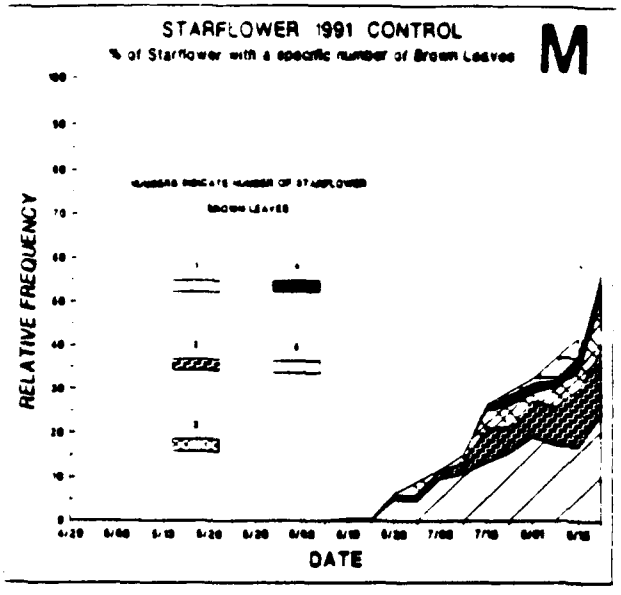

STARFLOWER 1988 ANTENNA
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
% of Starflower with a specific number of Brown Leaves
I
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 ANTENNA
% of Starflower with a specific number of Brown Leaves
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
% of Starflower with a specific number of Brown Leaves
K
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 ANTENNA
% of Starflower with a specific number of Brown Leaves
L
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 CONTROL
M
RELATIVE FREQUENCY
DATE

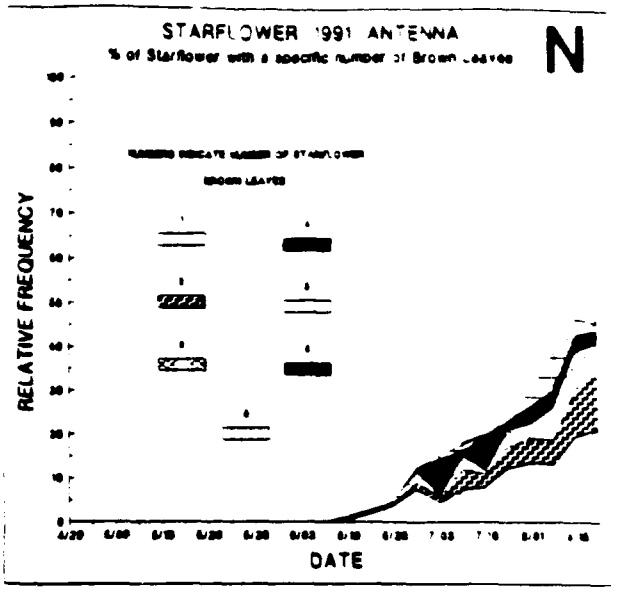
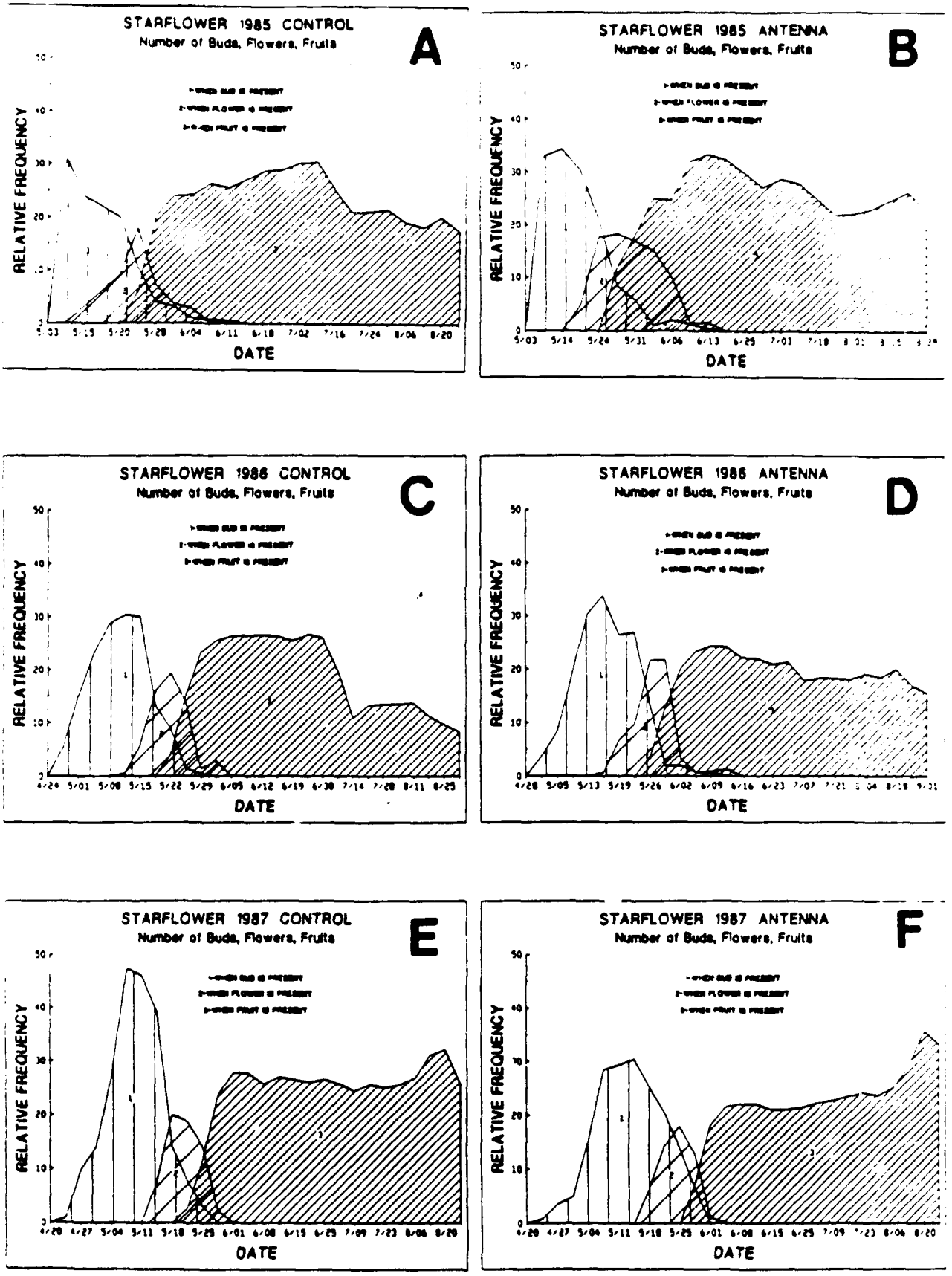
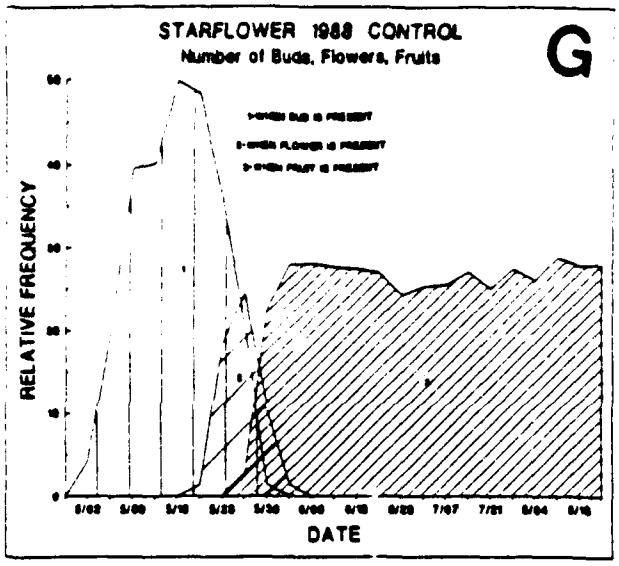
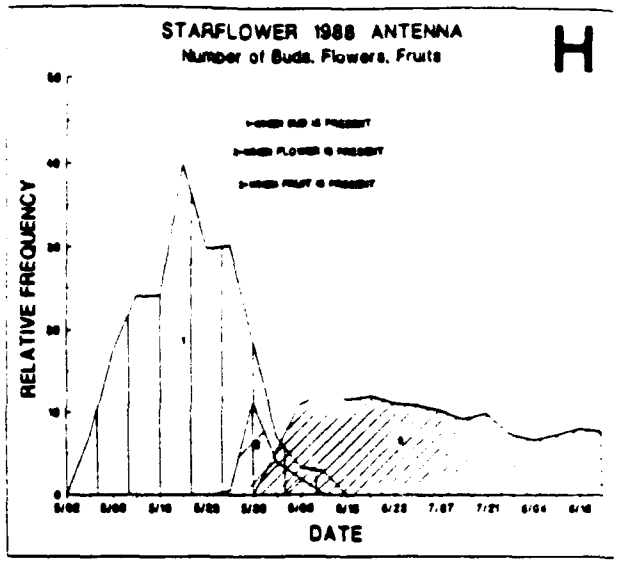

STARFLOWER 1991 ANTENNA
N
RELATIVE FREQUENCY
DATE

Figure 3.6: Comparison of the relative frequency and proportion of plants with one or more buds, flowers, and fruit by sampling date on the control site 1985 (A), 1986 (C), 1987 (E), 1988 (G), 1989 (I), 1990 (K), and 1991 (M); and the antenna site in 1985 (B), 1986 (D), 1987 (F), 1988 (H), 1989 (J), 1990 (L), and 1991 (N).




STARFLOWER 1988 CONTROL
Number of Buds, Flowers, Fruits
G
RELATIVE FREQUENCY
DATE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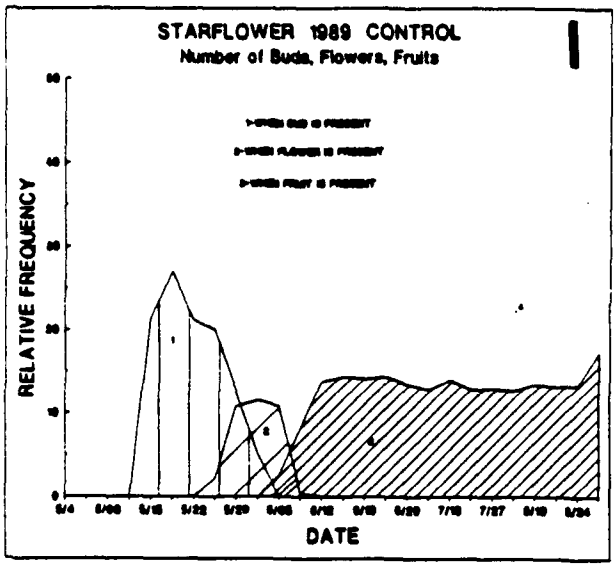
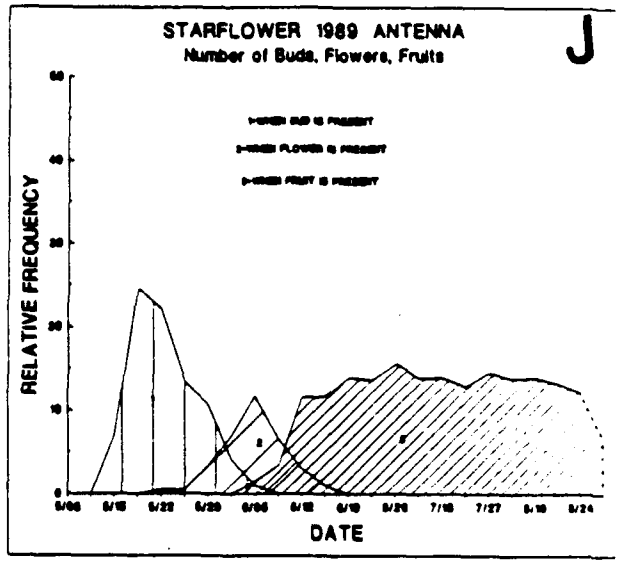
Number of Buds, Flowers, Fruits
H
RELATIVE FREQUENCY
DATE


STARFLOWER 1989 CONTROL
Number of Buds, Flowers, Fruits
I
RELATIVE FREQUENCY
DATE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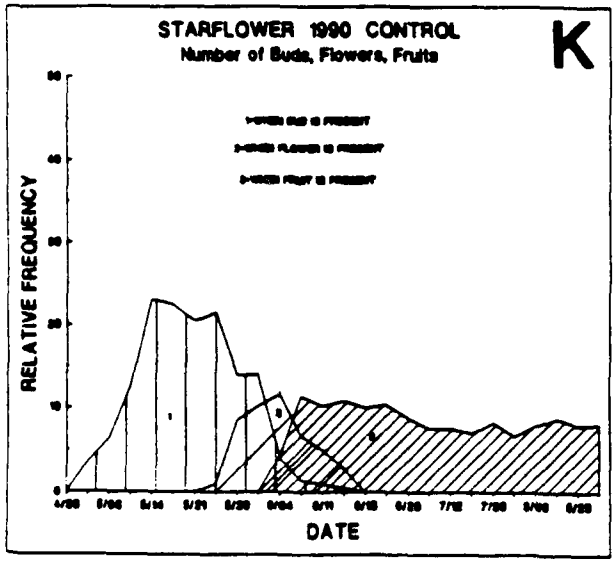
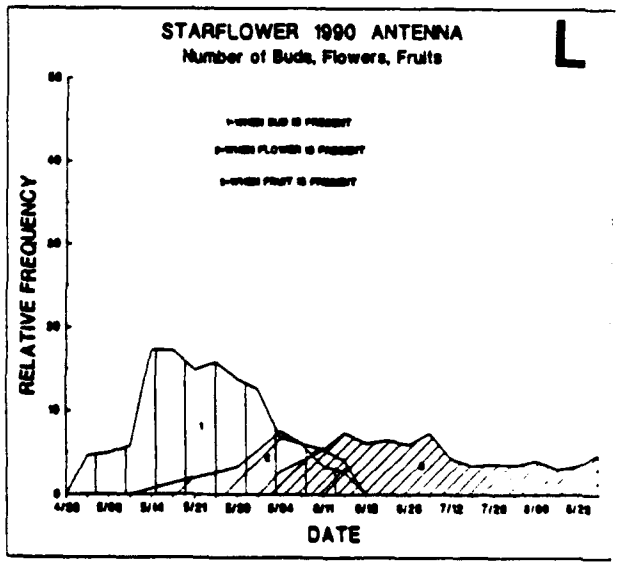
Number of Buds, Flowers, Fruits
J
RELATIVE FREQUENCY
DATE


STARFLOWER 1990 CONTROL
Number of Buds, Flowers, Fruits
K
RELATIVE FREQUENCY
DATE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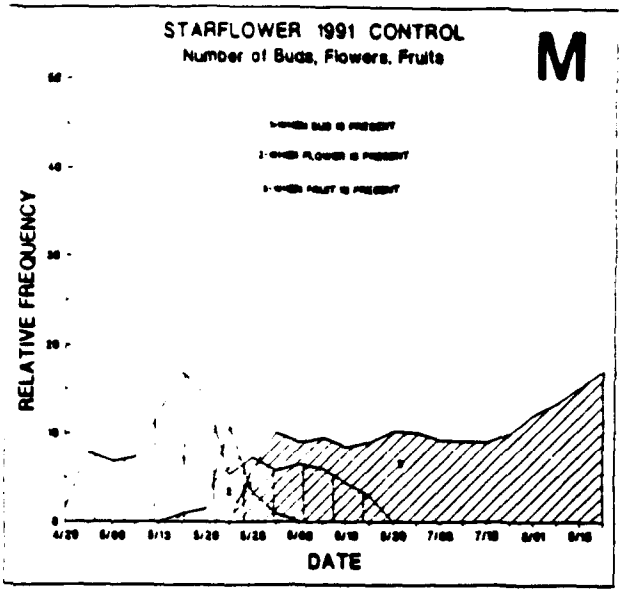
Number of Buds, Flowers, Fruits
L
RELATIVE FREQUENCY
DATE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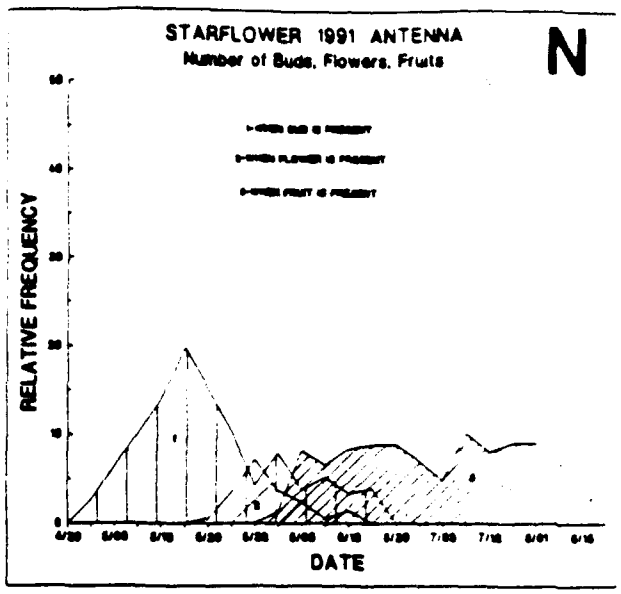
Number of Buds, Flowers, Fruits
M
RELATIVE FREQUENCY
DATE


STARFLOWER 1991 ANTENNA
Number of Buds, Flowers, Fruits
N
RELATIVE FREQUENCY
DATE

Because of the evident subplot variation along the sampling transect, additional information on the basal area and canopy coverage associated with each subplot was taken in 1989. Basal area by major tree species and total basal area were measured for each subplot using a 10 factor prism. Canopy coverage on the ground and at 4.5 feet were measured using a densiometer. This same information was used for the 1990 and 1991 analyses.

Table 3.2. Analysis of Covariance table for stem expansion, leaf expansion, and leaf area expansion.

Source of Variation	df	SS	MS	F
Year	4	SS_y	MS_y	MS_y/MS_{e1}
Covariates	#	SS_{cy}	MS_c	MS_c/MS_{e1}
Error 1 (P/Y)	40-#	SS_{e1}	MS_{e1}	
Site	1	SS_s	MS_s	MS_s/MS_{e2}
Site by Year	4	SS_{sy}	MS_{sy}	MS_{sy}/MS_{e2}
Covariates	#	SS_{cs}	MS_{cs}	MS_{cs}/Ms_{e2}
Error 3 (SxP/Y)	40-#	SS_{e2}	MS_{e2}	

In the initial analysis of variance without covariates, stem expansion, leaf expansion, and area expansion on the antenna site were significantly different from the control site (Table 3.3A) Year and site/year interactions were also determined to be significantly different (Table 3.3A). Prior to ANCOVA, scatterplots of soil temperature degree days running total versus the response variables indicated that the variation in the response variables increased with increasing soil temperature (e.g.non-constant variance). This problem was solved by taking the natural log of soil temperature degree days running total. Correlations were then calculated between starflower measurements and climatic and microsite variables. The variables were most highly correlated to leaf area expansion and leaf length expansion were 1) maximum solar radiation (SOLMX) (r=-0.44, -0.44, respectively), 2) natural log of soil temperature degree days running total at 10 cm (LST10DRT) (r=0.56, 0.62, respectively), 3) bigtooth aspen basal area (BTABA) (r=0.31, 0.30, respectively), and 4) northern red oak basal area (NROBA) (r=-0.31, -0.30, respectively). Interactions between the climate variables and microsite variables were also highly correlated to leaf area expansion and leaf length expansion (ie., LST10DRT/BTABA (r= -0.22, -0.19, respectively), and LST10DRT/NROBA (r=0.30, 0.30, respectively) SOLMX/BTABA (r= -0.31, -0.33, respectively)). Although not highly correlated to leaf area and leaf length expansion, the interaction SOLMX/NROBA (r= -0.02, 0.03, respectively) was used as a covariate to explain the high component of northern red oak trees on the control site. Due

Table 3.3. Results of ANCOVA (p values) to determine significant differences in stem expansion (STEM), leaf expansion (LGTH), and leaf area expansion (LAREA) between sites, years, and site by years.

A) No Covariates

Source of Variation	STEM	LGTH	LAREA
Year	0.00	0.00	0.00
Site	0.00	0.00	0.00
Site by Year	0.00	0.00	0.00

B) Covariates for Leaf Length (LGTH) and Leaf Area (LAREA). Natural log (Soil Temperature Degree Days Running Total) + Bigtooth Aspen Basal Area (BTABA) + Northern Red Oak Basal Area (NROBA) + Natural Log (Soil Temperature Degree Days Running Total at 10 cm)/BTABA + Natural Log (Soil Temperature Degree days Running Total at 10 cm)/NROBA + Maximum Solar Radiation/BTABA + Maximum Solar Radiation/NROBA.

Source of Variation	LGTH	LAREA
Year	0.00	0.00
Site	0.98	0.95
Site by Year	0.16	0.67

C) Covariates for Stem Length (STEM). - Natural log (Soil Temperature Degree Days) + Bigtooth Aspen Basal Area (BTABA) + Northern Red Oak Basal Area (NROBA) + Maximum Solar Radiation/BTABA + Maximum Solar Radiation/NROBA.

Source of Variation	STEM
Year	0.00
Site	0.99
Site by Year	0.00

to multicollinearity among these variables only BTABA, NROBA, and their corresponding interactions were used in the analysis. The use of these covariates explained significant amounts of variation in leaf area expansion and leaf length expansion between sites and among site by years but not among years (Table 3.3B).

The same covariates used for leaf length and area expansion could not be used for stem expansion. The reason for this is unknown, however, stem expansion may be related to the amount of carbon stored in the roots from the previous year and to initial seasonal conditions. The variables most highly correlated to stem expansion were 1) maximum solar radiation (SOLMX) (r=-0.15), 2) natural log of soil temperature degree days running total at 10 cm (LST10DRT) (r=0.20), 3) bigtooth aspen basal area (BTABA) (r=0.23), and northern red oak basal area (NROBA) (r= -0.21). Interactions between the climate variables and microsite variables were highly correlated to stem expansion SOLMX/BTABA (r=-0.20) and SOLMX/NROBA (r=0.04). All these variables were used in the covariate analysis. These covariates explained significant amounts of variation in stem expansion between sites only (Table 3.3C). Yearly differences and site by year interactions could not be explained. The addition of other climatic and microsite factors as covariates did not yield better results. These covariates are the same ones used in the analysis in 1990. Information on the strength of the ELF field was not available for this years analysis and thus was not included. Once this information becomes available it will be used to determine if the field strengths can explain the site by year interactions and the year differences. Monitoring the effects of ELF fields on stem, leaf, and area expansion will continue.

Morphological Characteristics

Observations in the past years suggested a clonal difference between the population of starflower on the antenna site versus the population on the control site. In 1990, starflower plants and soils from each site were collected off the herbaceous transects and reciprocally transplanted on to the other site. Plants were randomly chosen from each site and placed in the same light regime on the other site. then measured in early September to determine if there were morphological differences between the two sites. In 1990, the transplant study indicated that there was a significant reduction ($p < 0.05$) in the stem length of plants taken from the control and planted on the antenna site versus average stem lengths on the control site. Number of leaves, leaf lengths, and leaf widths were not statistically different between the sites. At this time, there is no explanation for these results. In 1991, none of the transplants could be found on either site, thus this study was not continued. It is believed that the transplants on both sites did not produce a rhizome at the end of the growing season in 1990. This was probably due to transplanting shock and/or to other climatic factors.

Three buds per plant were observed on both the antenna site and the control site this year (Figure 3.1G) but during the period of April 29 and June 1 the number of plants with

two buds fluctuated considerably. This fluctuation was attributed to herbivores. Plants on the antenna site produced the same number of flowers (Figures 3.2G). Plants with three fruit were observed on the antenna site but not on the control site (Figures 3.3M and 3.3N). The antenna site exhibited a smaller proportion of plants (60%) that produced yellow leaves than plants on the control site (75%) (Figures 3.4M and 3.4N). The percent of plants with brown leaves were similar between the antenna and the control site (Figures 3.5M and 3.5N). Except for the proportion of with yellow leaves, similar relationships were seen in the 1985, 1987, 1988, 1989, and 1990 growing seasons. The effects of ELF fields on these morphological characteristics are not evident at this time.

Using regression analysis, linear equations were fit to observations of leaf area using leaf length and leaf width measured on destructively sampled starflower plants off the herbaceous reserves for each year (1986-1991) on each site (Table 3.5).

Table 3.5. Leaf area (LA) equations for each site in each year and for all sites and all years using leaf width (Lw) and leaf length (Ll).

Site (Year)	Equation	$S_{y.x}$[1]
Control Site (1986)	LA = 0.09 + 0.55 (Lw x Ll)	0.20
Control Site (1987)	LA = 0.11 + 0.56 (Lw x Ll)	0.18
Control Site (1988)	LA = 0.40 + 0.52 (Lw x Ll)	0.68
Control Site (1989)	LA = 0.05 +.0.57 (Lw x Ll)	0.18
Control Site (1990)	LA = 0.08 + 0.56 (Lw x Ll)	0.16
Control Site (1991)	LA = 0.13 + 0.56 (Lw x Ll)	0.21
Antenna Site (1986)	LA = 0.13 + 0.55 (Lw x Ll)	0.26
Antenna Site (1987)	LA = 0.13 + 0.56 (Lw x Ll)	0.34
Antenna Site (1988)	LA = 0.32 + 0.52 (Lw x Ll)	0.60
Antenna Site (1989)	LA = 0.05 + 0.56 (Lw x Ll)	0.24
Antenna Site (1990)	LA = 0.15 + 0.54 (Lw x Ll)	0.37
Antenna Site (1991)	LA = 0.12 + 0.54 (Lw x Ll)	0.35

[1] Standard error of regression

The independent variable of leaf width x leaf length explained over 98 percent of the variation in leaf area for both sites in 1986, 1987, 1989, 1990, and 1991. Ninety-two and 96 percent of the variation in leaf areas was explained using the variable leaf width x leaf length for the control and the antenna, respectively, in 1988. Higher standard errors occurred with the development of the 1988 curves (Table

3.5). Possible causes of increased error in 1988 were attributed to inaccuracies in leaf length and leaf width measurements and/or leaf sampling techniques in the field. These problems seem to be corrected for subsequent year's data.

Regression coefficients (intercepts and slopes) were tested to determine if there were significant differences ($p < 0.05$) between sites (antenna vs control) and among years. Site-year interactions were also examined. In 1991, significant yearly ($p < 0.001$) and site ($p < 0.05$) differences in both the slopes and the intercepts were observed. Intercepts for the antenna and control sites in 1988 were again significantly greater than for 1986, 1987, 1989, 1990, and 1991 and the intercept for 1989 was significantly lower than all other years. Slopes for the antenna and control sites were significantly lower in 1988 than for 1986, 1987, 1989, 1990, and 1991. These differences may be due to the increase in the amount of solar radiation in 1988 compared to other years (Element 1, this report). Leaf areas will continue to be measured and prediction equations developed using leaf length and leaf width.

Summary

In 1991, significant variation in stem expansion, leaf expansion, and leaf area expansion between the antenna and the control site can be explained using microsite basal areas, soil temperature degree days running total at 10, maximum solar radiation, and interactions between these variables. These covariates also explained significant variations in leaf expansions and leaf area expansions among site by year interactions. There were, however, significant yearly differences on all three response variables, stem length, leaf length, and leaf areas. Our conclusion at this time is that ELF fields are not significantly influencing starflower on the antenna site. Even though timing of flowering and fruiting in 1990 was observed to be before maximum bud break and flowering, these differences were not observed in 1991. Analysis will continue during the 1992 growing season.

Element 4. MYCORRHIZAE CHARACTERIZATION AND ROOT GROWTH

Mycorrhizae of plantation red pine seedlings have been chosen as sensitive biological indicators to reflect perturbations which might be caused by ELF fields. Mycorrhizae are symbiotic structures representing a finely balanced physiological relationship between tree roots and specialized fungi, providing mutual benefit to both partners of the symbiosis. Mycorrhizal fungi are obligately bound to their host requiring photosynthate from the tree for their energy source. In return, the matrix of mycorrhizal fungus mycelium which permeates the forest floor and mineral soil from colonized roots provides the host tree with minerals and water more efficiently than without its fungal partner. Although many types of mycorrhizae occur on these sites, this study will examine only ectomycorrhizae fungi formed on red pine root systems.

Mycorrhizal associations are a major part of a forest ecosystem and are likely to be sensitive indicators of subtle environmental perturbations. Mycorrhizal fungi are obligate symbionts, directly dependent on their partner's physiology for their health. Thus mycorrhiza formation and numbers will be sensitive to factors affecting either the fungus component or the host plant component.

Mycorrhizae have been selected for evaluation in other studies which require sensitive indicators of subtle environmental changes. Recent studies were designed to monitor the effects of acid rain on the forest ecosystem using mycorrhizal numbers as the parameter of assessment (Reich *et al.* 1985, Shafer *et al.* 1985, Stroo and Alexander 1985, Dighton and Skeffington 1987). Similar studies have examined mycorrhizae and how they are affected by ozone and air pollution (Kowalski 1987, Reich *et al.* 1985, Mejstrik and Cudlin 1987) and heavy metal buildup in soils (Jones and Hutchinson 1986). Extremely low frequency fields could detectably alter the more discriminating mycorrhizal fungus component. Data regarding mycorrhizae may also be used to substantiate responses seen in other measures of tree productivity.

Populations of mycorrhizae on each red pine plantation site are compared at monthly intervals during the growing season (May-October) and with corresponding monthly intervals during the growing season from previous years. The basic experimental units are individual red pine seedlings. Mycorrhizae are categorized into morphological types produced by different fungal associations on red pine seedlings. Changes in both the frequency of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling are quantified for analysis both within and among years as well as among sites. Data for analysis are expressed as the total number of mycorrhizae

per gram of seedling root mass (oven dry weight (o.d.w.) 60°C). The working null hypothesis states that there are no differences in population densities of different types of mycorrhizal root tips on red pine seedlings at the Ground Antenna and Control sites, before or after the ELF Antenna becomes operational. Other changes that could occur are reflected by possible alternative hypotheses such as; 1) shifts in population species composition and 2) changes in the character of mycorrhizal morphology type.

Sampling and Data Collection

In conjunction with Element 2, Tree Productivity, fifteen red pine seedlings per site (five per plot per site) were sampled for six months (May-October) during the 1991 growing season, as was done the previous five years. Seedlings for mycorrhizal analysis were simultaneously measured for above- and belowground growth parameters and moisture stress. To retrieve mycorrhizae-bearing lateral roots, the seedling's root system was excavated using a shovel and produced a soil sample approximately 22 cm in diameter and 22 cm deep. Red pine seedling fine (< 5mm) roots were extracted from this sample in the field to obtain approximately 30 to 60 cm of total root length. Lateral roots from each seedling with adherent soil were wrapped tightly in individual plastic bags, placed in a cooler and transported to the laboratory where they were refrigerated. Within two to three days the lateral roots were rinsed first in a small volume of distilled water (1:1 water to root/soil volume) for rhizosphere soil pH determination, then washed gently in tap water, placed in a fresh volume of tap water and refrigerated. Approximately 0.25 g roots (fresh weight) per sample were removed at this time for actinomycete enumeration (ELF, Litter Decomposition and Microflora Study). Counting mycorrhizal tips was begun immediately with counts completed within two weeks of field sampling.

A shallow white pan containing a small amount of water was used during the root sectioning and counting operation. The roots were cut to obtain 30 - 3 cm segments. As each 3 cm root segment was counted, its diameter and number of mycorrhizae were recorded. A mycorrhiza is defined, in this study, as a terminal mycorrhizal root tip at least 1.0 mm in length; hence a mature dichotomously branched mycorrhizal root tip would be tallied as two mycorrhizae. Upon completion of counting segments were collectively dried at 60°C to constant mass and weighed. Mycorrhiza counts for each 3 cm root segment are expressed as mycorrhizae per gram (o.d.w.) of dry root. This measure has been used in other root studies examining mycorrhizae dynamics in forest ecosystems (Harvey *et al.* 1987).

The most common mycorrhizae on these sites continue to be represented by fairly uniform morphologies. They range

in color from a tan to a deep red-brown color and are formed primarily by *Thelephora terrestris* and/or *Laccaria laccata* (*sensu lato*, Fries and Mueller 1984). These mycorrhizae have been designated as Type 3 mycorrhizae. Many of the mycorrhizae have acquired a nearly black to deep jet-black color due to colonization by *Cenococcum graniforme*, an abundant mycorrhizal fungus in the original and surrounding hardwood forests, which were designated as Type 5 mycorrhizae. White to tan floccose forms are occasionally found, presumably colonized by *Boletus, Hebeloma, Paxillus* or *Suillus* spp., which have been designated as Type 6 mycorrhizae. Though variations occur within mycorrhizal morphology types, all fit within the grouping of these three main types. A dissecting microscope was used, but was not always necessary, to distinguish the mycorrhizal types. Morphology types are tallied separately and then totaled for each seedling. Non-mycorrhizal root tips are easily distinguishable as white root tips composed entirely of plant tissue, obviously lacking a fungal component.

Descriptions of Red Pine Mycorrhizal Morphology Types

Type 3 Mycorrhiza

Macroscopic: Light buff to dark red brown, sometimes nearly black, usually lighter at the apex; 2-10 mm long x 0.25-1.0 mm diameter; mono- or bipodal, occasionally multiply bifurcated and in mass forming coralloid clusters; plump and straight when short, but spindly and often crooked when long, usually somewhat constricted at the base.

Microscopic: Surface hyphae sparse, 2-3 um diameter, bearing clamps, setae scattered, often clustered in bunches of 4-8, mostly 50-80 um long; mantle 10-20 um thick, thinner over apex, hyphae forming conspicuous interlocking, "jig-saw puzzle-like" pattern; cortical cells red-brown except over apex where they are colorless; Hartig net hyphae bulbous and also forming interlocking pattern.

Comments: This is the most common type of mycorrhiza and was found originally on nursery red pine seedlings. The causal fungi, as evidenced by cultural isolation, are most often *Laccaria laccata* (*sensu lato*) and *Thelephora terrestris*, though other fungi may also produce similar mycorrhizae. It is worth noting that *L. laccata (sensu lato)* abounds in the surrounding forests and fruits abundantly on the plantation sites. This fungus might therefore be expected to maintain its dominance in the plantation seedlings. *Thelephora terrestris* has also been observed fruiting on the plantation sites.

Type 5 Mycorrhiza

Macroscopic: Black, sometimes with lighter apex; usually fuzzy with abundant attached, coarse hyphae; 1-3 mm long x 0.5-10 mm diameter; mono or bipodal, seldom multiply bifurcated; often appearing as if dark hyphae are enveloping Type 3 mycorrhizae.

Microscopic: Surface hyphae dark-brown to black, 3-6 um diameter, septate; setae arising from central stellate points of interlocking surface hyphae, setae 100 um or greater in length; mantle 10-30 um thick, mantle surface of coiled and interlocking hyphae; cortical cells dark and covered directly with hyphae of the same type observed with Type 3 mycorrhizae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This is a later successional stage mycorrhiza, appearing as a dark sheath over an earlier developed mycorrhiza. The causal fungus is *Cenococcum graniforme*, which is commonly isolated from these mycorrhizae. Hypogeous fruit bodies of *Elaphomyces* spp., the anamorph of *C. graniforme*, have been collected in the surrounding forest, indicating that adequate inoculum is available.

Type 6 Mycorrhiza

Macroscopic: White to light gray-brown, mottled and silvery; 2-5 mm long x 0.5-1.0 mm diameter; abundant loosely-bound surface hyphae often binding soil matter; mono- or bipodal often in large coralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing freed individual mycorrhizae to float.

Microscopic: Surface hyphae colorless, abundant, septate or not, 3-6 um diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 24-100 um thick, cortical cells red-brown covered with interlocking hyphae similar to Type 3; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This also appears to be a later successional stage mycorrhiza type forming a sheath over an earlier developed mycorrhiza. Presumably the responsible fungi colonize new root tips as well. Based on cultural characteristics of isolated fungi, the causal fungi probably belong to the families Boletaceae, Cortinariaceae or Paxillaceae. Fruiting bodies of these families were common in the original forest and fruit abundantly in the surrounding forest, providing adequate and readily available inoculum.

Statistical Analysis

Though red pine seedlings were outplanted on the study sites in June 1984, data from that year are not being compared with subsequent years for two reasons. First, 1984 was the year of plantation establishment; nursery seedlings are small and planting shock is known to have a significant effect on seedling root systems. Second, ambient weather and soil data was not available for 1984. For all years following 1984, total mycorrhizae per gram of dry root (o.d.w.) has been used to compare sites and sites within and among years. A nested analysis of variance was used to test these factor levels. The error term used to test site differences was plot within site. The error term used to test yearly differences was month within year and the error term used to test site by year interactions was month within year by site. These error terms were used because of the occurrence of unequal variances in the total number of mycorrhizae per gram of dry root among plots and among months. We also made the following assumptions: 1) site differences were mainly due to plot differences, 2) yearly differences were mainly due to monthly variations, and 3) site by year differences were mainly due to monthly variations within year by site. A significance level of $p=0.05$ with the Student Newman Keuls's Multiple Range Test was used to detect significant differences among means. To facilitate this, data on total mycorrhizae per gram of dry root mass were analyzed using analysis of covariance, with weather and soil ambient variables applied as covariates.

Progress

Non-mycorrhizal root tips were not encountered in the 1991 season. Since 1985 non-mycorrhizal root tips declined, until 1987 when none were observed for the final month at the Ground and Control sites, and for the last four months at the Antenna site. Non-mycorrhizal roots were not encountered in 1988, 1989, nor in 1990. This steady decline in uncolonized root tips is likely a function of seedling maturation, and indicates that seedlings are becoming fully adapted to native soil microflora. Non-mycorrhizal root tips remain a morphological type of interest, and will continue to be monitored in future years, in case (hypothetically) seedlings undergo a reversion in maturity due to ELF field effects.

Type 3 mycorrhizae in 1991 continued to be the major mycorrhizal type on red pine seedling root systems at all sites (Figures 4.1 and 4.2). This year, total numbers of mycorrhizae on the Control site were greater from July to October than numbers on the Antenna and Ground sites. During the 1991 growing season there was a distinct increase in mycorrhizal numbers in July on all sites (Figures 4.1 and 4.2). Numbers only decreased in October on the Ground site. Increases may be due to increased temperatures and

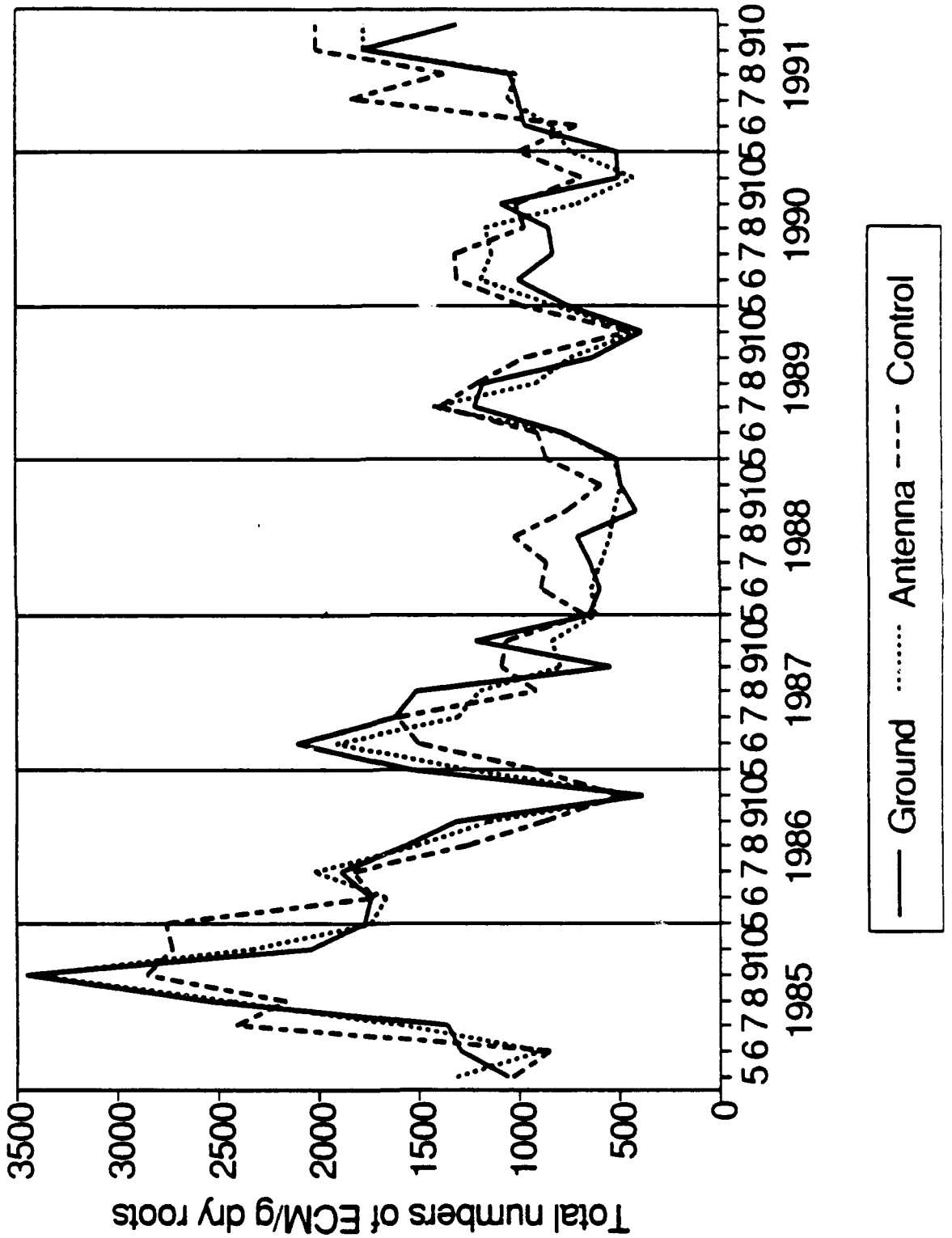
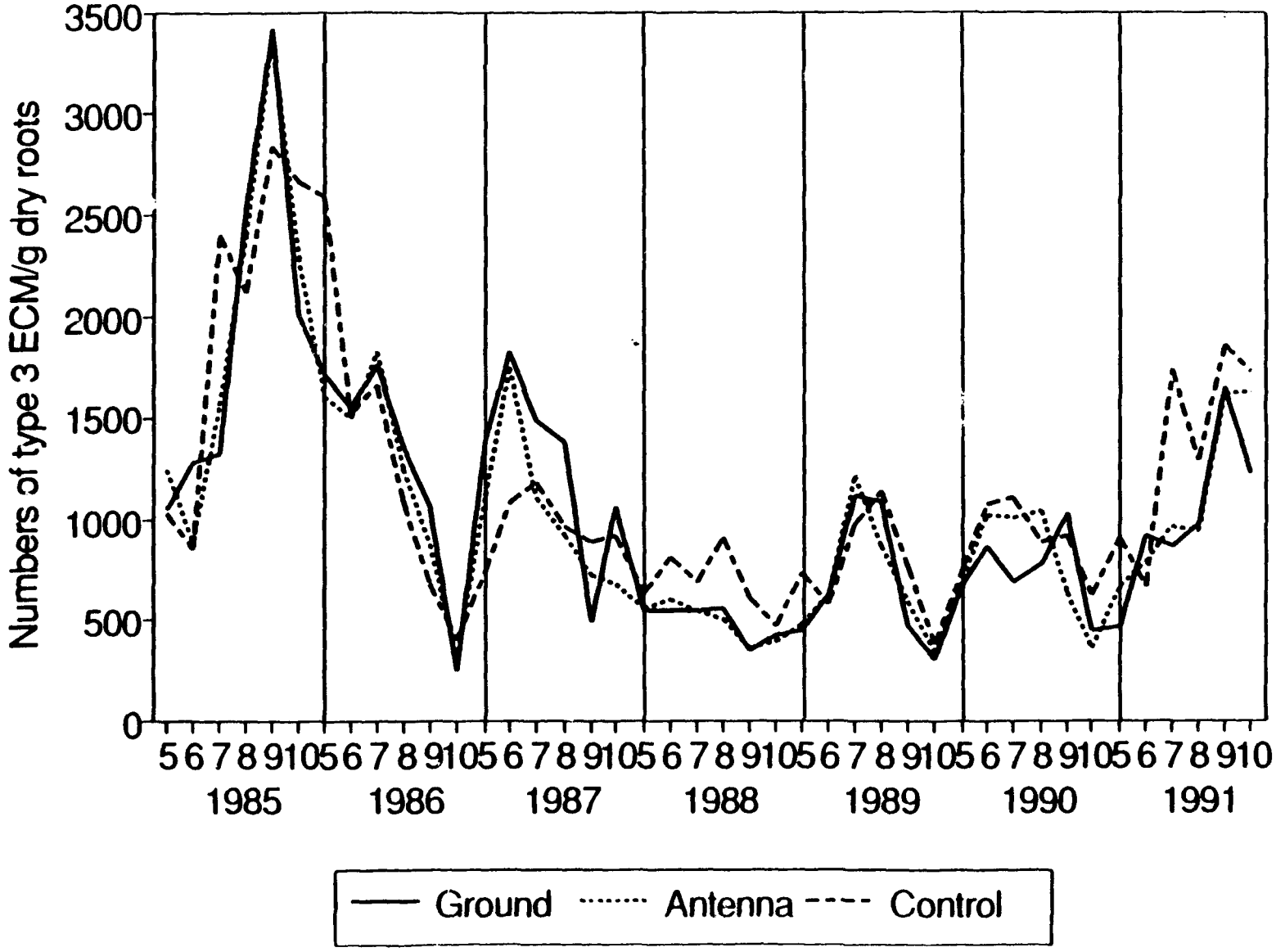


Figure 4.1: Yearly and monthly comparisons of the total number of mycorrhizal root tips per gram of dry root.

Figure 4.2: Yearly and monthly comparisons of the number of Type 3 mycorrhizal root tips per gram of dry root.



precipitation in 1990 and 1991 (see Element 1) or to soil nutrient fluctuations (see Element 2). Numbers of mycorrhizal root tips in 1991 were not significantly different from numbers in 1987, 1988, 1989, and 1990.

Type 5 mycorrhizae decreased in June, then increased in July on all sites (Figure 4.3). This year, numbers of type 5 mycorrhizae were comparable to 1988, except on the Control and Antenna sites in September and October. Statistical comparisons from year to year for any site and month demonstrate that numbers in 1991 were most like numbers in 1990, 1989, 1988, and 1987. The Control site had significantly higher numbers of Type 5 mycorrhizae in October than the Antenna and Ground sites. As with Type 3 mycorrhizae, differences are attributed to fluctuations in increases in mean air temperatures and precipitation amounts in the preceding months.

Type 6 mycorrhizae are the least common type encountered on red pine seedlings for all study sites (Figure 4.4; note different scale of the Y axis compared with Figures 4.1, 4.2, and 4.3). They were first observed in late 1984 on very few seedlings. In 1985, Type 6 mycorrhizae were recorded only in July and August on the Control site. In 1986, no seedlings were found with Type 6 mycorrhizae. In 1987 the occurrence of Type 6 mycorrhizae was still infrequent and sporadic (Figure 4.4), but they were found often enough on all sites (but not all months) to make comparisons among sites for the year. In 1988, numbers of Type 6 mycorrhizae were similar to the previous year, but higher numbers are being recorded, especially later in the season. In only two months of 1988 were differences between sites significant: in May the Ground and Antenna sites had lower numbers of Type 6 mycorrhizae per gram than the Control site, and in September the Ground site had lower numbers than the Antenna site while not differing from the Control site. In 1989, however, numbers of Type 6 mycorrhizae declined with only the Control and Ground site having similar numbers in May and the Control and Antenna site having similar numbers in July (Figure 4.4). In 1990, numbers of Type 6 mycorrhizae were similar to 1989 except for September when numbers increased on the Ground site. This later stage mycorrhizal type would be expected to develop sooner on the best of site (Control site), where tree growth had been advancing more quickly (see Element 2). In 1991, Type 6 mycorrhizae were not evident. Numbers of Type six have decrease since early 1989. Reasons for this are unknown. Differences among months may be due to individual soil properties associated with each seedling sampled and not to climatic characteristics.

At this time, there does not appear to be any affect of ELF fields on the number of mycorrhizal root tips per gram of dry root. In 1989, site differences were the least distinct of all years. If there are changes in mycorrhizal

Figure 4.3: Yearly and monthly comparisons of the number of Type 5 mycorrhizal root tips per gram of dry root.

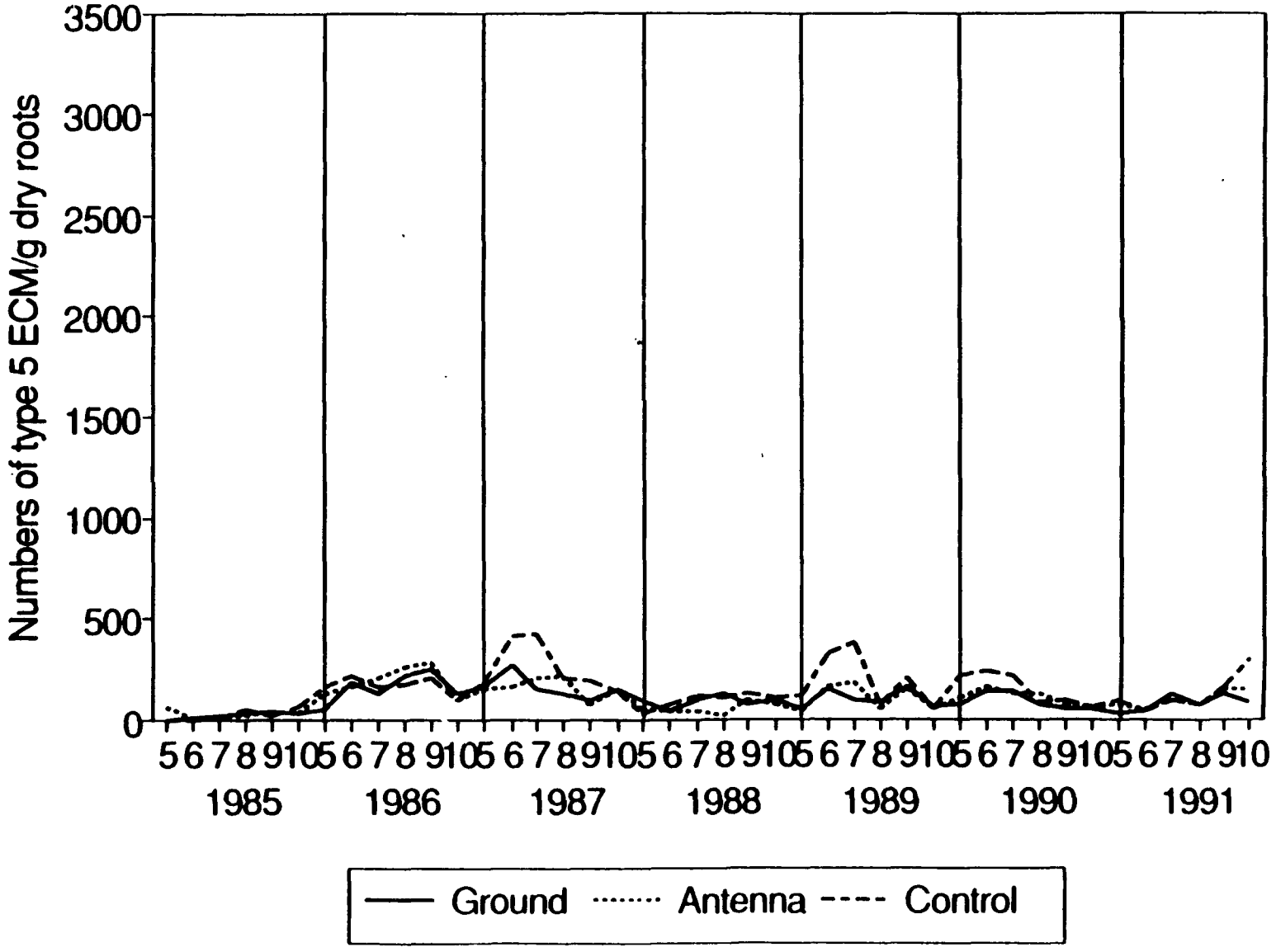
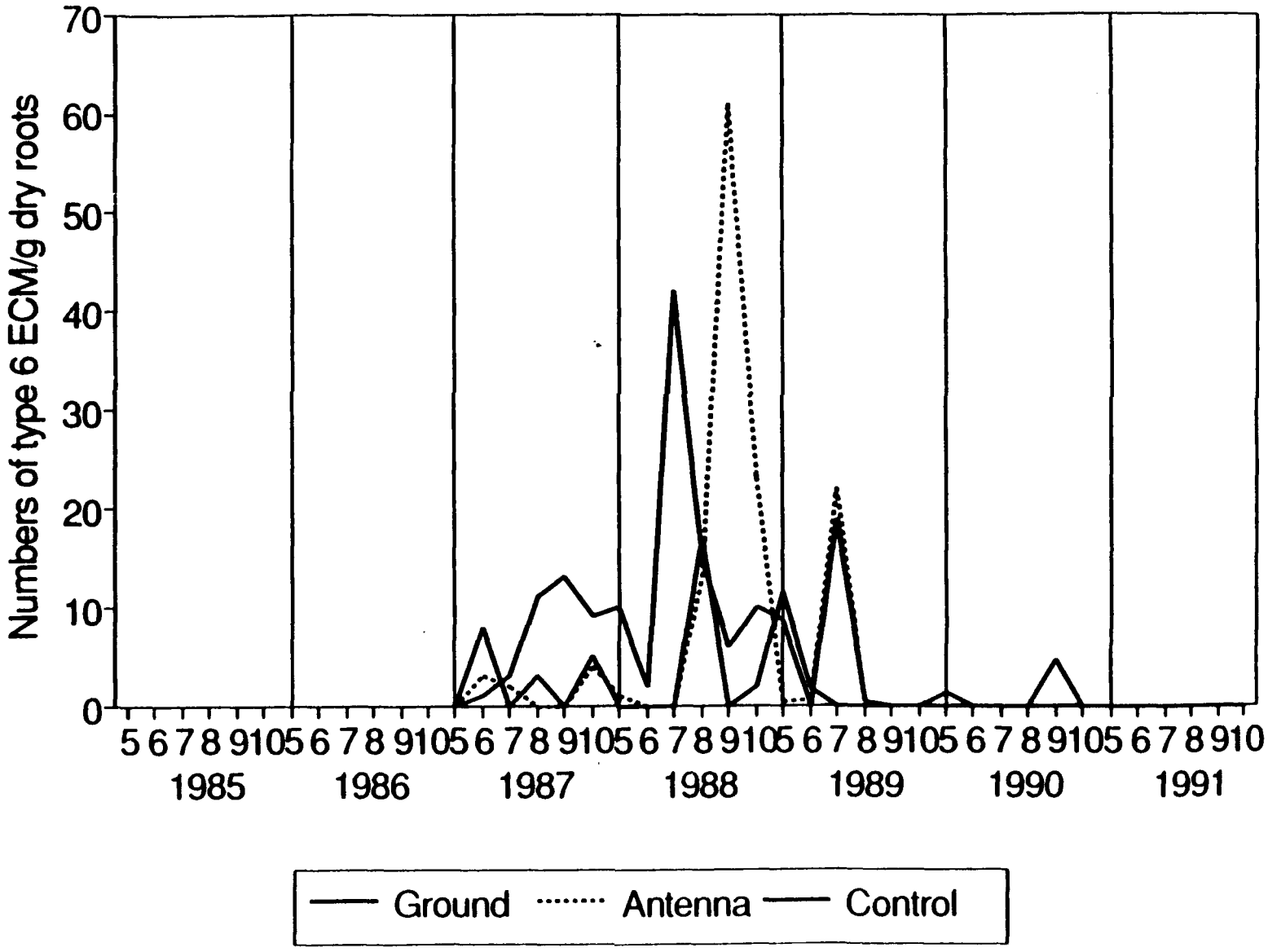


Figure 4.4: Yearly and monthly comparisons of the number of Type 6 mycorrhizal root tips per gram of dry root.



numbers due to ELF fields this should become evident within the next few years since the ELF Antenna became fully operational in September, 1989.

Covariate Analysis

Covariate analysis was used to explain some of the differences in numbers of total mycorrhizae per gram dry root among sites, years, year by site interactions by taking into account the variation in ambient weather and soil conditions. Means and sums of ambient variables represent a period of approximately 30 days prior to each mycorrhizae sampling date. The complete list of ambient variables used in the analysis is shown in Table 4.1.

Correlations were performed to determine which ambient variables were most likely to serve as covariates. Correlation coefficients (r) for total mycorrhizae per gram of dry root with the ambient variables are in Table 4.1. Lower correlation coefficients were observed this year than in previous years. Reasons for this are unknown at this time. A wider variation in weather patterns may be needed to predict major changes in mycorrhizal numbers or some other methodology to model daily changes in weather over the sampling period.

Analysis of variance (ANOVA) was performed with seven years of data (1985-1991) to detect differences between or among various factors, and their interactions, on total mycorrhizae per gram of dry root. Without covariates, mycorrhizal numbers were not significantly different ($p<0.05$) among sites and among site by year interactions (Table 4.2). Significant differences ($p<0.01$) among years were detected. Significantly fewer numbers of mycorrhizae occurred in years 1987, 1988, 1989, 1990, 1991 compared with years 1985 and 1986. Differences may be due to the acclimation of seedlings to their habitat or to monthly and yearly changes in ambient conditions, as discussed above.

To test whether the addition of a covariate explained yearly differences in mycorrhizal numbers analysis of covariance (ANCOVA) was performed with the five years of collected data. Table 4.2 lists probability (p) values (significance of the F statistic) after analysis of covariance, using five significantly correlated ($p<.001$) ambient parameters and age of the seedling. Age was used in the analysis this year to determine if the natural aging process of the seedling could explain significant amounts of variation in the number of mycorrhizae per gram of dry root. The addition of two variables, total Precipitation (PRCTOT) and maximum soil temperature at 5 cm (ST5MX), in the analysis was also tested. In all cases, although p values for site factors and site and year interactions changed, yearly differences could not be explained. The use of number of days, precipitation events are greater than 0.10

Table 4.1. Pearson correlation coefficients (r) calculated for total mycorrhizae per gram of seedling root with ambient parameters for seven years (1985 through 1991).

Ambient Parameter	Correlation Coefficient
AT=mean daily air temperature	.0812***
ATMN=mean minimum daily air temperature	.1137***
ATMX=mean maximum daily air temperature	.0452·1
ATDD=mean air temperature degree days	.0361NS
ATDDRT=air temperature degree days running total	-.0406·1
ST5=mean soil temperature at 5 cm	.0916***
ST5MN=mean minimum soil temperature at 5 cm	.0855***
ST5MX=mean maximum soil temperature at 5 cm	.0971***
ST5DD=mean soil temperature at 5 cm degree days	.0715**
ST5DDRT=soil temperature at 5 cm degree days running total	.0579**
ST10=mean soil temperature at 10 cm	.0913***
ST10MN=mean minimum soil temperature at 10 cm	.0898***
ST10MX=mean maximum soil temperature at 10 cm	.0931***
ST10DD=mean soil temperature at 10 cm degree days	.0720***
ST10DDRT=soil temperature at 10 cm degree days running total	.0597**
PRCDAV=mean daily precipitation	.0450·1
PRCMNDAV=mean minimum daily precipitation	.0716***
PRCMXDAV=mean maximum daily precipitation	.0495*
PRCTOT=total precipitation	.1249***
PRC.01=number of days precipitation events > 0.01 cm	.1248***
PRC.10=number of days precipitation events > 0.10 cm	.1447***
SM5=mean soil moisture at 5 cm	-.0305NS
SM5MN=mean minimum soil moisture at 5 cm	-.0356NS
SM5MX=mean maximum soil moisture at 5 cm	-.0191NS
SM10=mean soil moisture at 10 cm	-.0165NS
SM10MN=mean minimum soil moisture at 10 cm	-.0577**
SM10MX=mean maximum soil moisture at 10 cm	.0385NS
Seedling AGE	-.2808***

*** Indicates significant correlation ($p<0.001$)
** Indicates significant correlation ($0.001<p<0.01$)
* Indicates significant correlation ($0.01<p<0.05$)
·1 Indicate significant correlation ($0.05<p<0.10$)
NS Indicates non-significant correlation ($p > 0.10$)

cm (PRC.10) in the covariate analysis produced significant year by site interactions.

Of the five ambient parameters used as covariates the one decreasing the site differences and the site and year interaction differences the most was total precipitation (PRCTOT). This ambient parameter is most likely to affect seedling root growth and mycorrhizal development because of the effect of drought on mycorrhizal fungi. It is believed that some fungi have the ability to enhance root processes during droughty climate. It appears, however, that on these sites mycorrhizal numbers increase with increases in precipitation. Monthly fluctuations within each growing season may be more important to mycorrhizal numbers than yearly differences in mean climatic data.

Table 4.2. Comparison of p values (significance of F) for total mycorrhizae per gram of seedling root data (1985 through 1991 after multiple analysis of covariance (ANCOVA) using some of the highly correlated (p<.001) ambient parameters.

COVARIATE	SITE	YEAR	YEAR x SITE
No Covariate	.073	.000	.087
AGE	.142	.000	.087
PRC.01[1/]	.211	.002	.061
PRC.10	.036	.004	.013
PRCTOT	.696	.002	.082
ATMN	.075	.000	.085
ST5MX	.183	.000	.096
PRCTOT + ST5MX	.809	.000	.082

[1/] See Table 4.1 for key to abbreviations of ambient parameters.

Summary

Although there was a mean increase in mycorrhizae numbers from 1988 to 1991, no significant differences in mycorrhizae numbers per unit weight of seedling root among sites and among site by year interactions were detected

using analysis of variance. Use of covariates did not reduce the differences among years. It may be that refinements in the analysis through the use of modeling appropriate temporal relationships between ambient data and seedling growth processes may help reduce differences among years.

The ELF Antenna system has been operational since the fall of 1989. If there were ELF effects on mycorrhizae numbers, the most important source of variation attributable to these effects would be the site by year interaction; numbers of mycorrhizae from years 1990 and 1991 on the Antenna and/or Ground site(s) would be significantly different than the numbers on the Control site or from prior years information. This was not the case. Detection limits calculated with three years of data prior to the fully operational ELF Antenna (1985, 1986, 1987) indicated that an overall difference of approximately 10 to 15 percent was necessary to recognize a significant difference among sites, and an overall difference of approximately 15 to 25 percent would be necessary to identify a significant difference among years and among site by year interactions.

Additional years information is needed to fully assess the long term effects of ELF fields on mycorrhizal root production. With refinements in the ambient parameters, as mentioned above, and their application to the analysis, detection limits will probably decrease. Findings, thus far, support the proposal that mycorrhizal symbiosis between tree roots and fungi can indeed be used as a sensitive indicator of subtle environmental changes.

Element 5. LITTER PRODUCTION

Litter fall and decomposition is important in the transfer of nutrients and energy within a vegetative community. The sensitivity of foliage production to both tree physiological changes and non-independent external climatic conditions make it a good indicator of possible ELF field effects on trees. Since litter samples can be gathered at frequent intervals, they provide an estimate of change in canopy production. Additionally, leaf samples taken during the growing season for nutrient analysis and weight determination would monitor nutrient accumulation and subsequent nutrient translocation from the foliage to the branches prior to leaf fall. This physiological process is also sensitive to environmental stress and would be a potential indicator of ELF field effects.

The objective of this element is to obtain information on total litter weight and nutrient content, and foliar nutrient levels of northern red oak during the growing season on the antenna and control plots prior to the operation of the ELF communication system. Two overall null hypotheses will be tested in this study.

H_0: There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

H_0: There is no difference in the foliar nutrient concentrations of northern red oak trees before and after the ELF antenna becomes operational.

Each year prior to an operational antenna (1984-1986), a baseline relationship of the ecological systems was determined whether there was any difference in the total weight of litter fall and foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for these analyses shown below (Table 5.1). Previous ELF annual reports have shown that no appreciable differences in these stand components were evident between these two sites prior to the onset of antenna operation.

Sampling and Data Collection

Five $1m^2$ meter litter traps are being used to monitor tree litter production on each permanent measurment plot at the antenna and the control sites. Litter was collected monthly during the summer and weekly after the onset of leaf fall in early September. Crown nutrient concentrations and translocation in northern red oak leaves are being examined by collecting foliage samples at both the antenna and control site during the summer months. An analysis of stem diameter data indicated that sampling trees of 15 cm, 21 cm and 32 cm

Figure 5.1

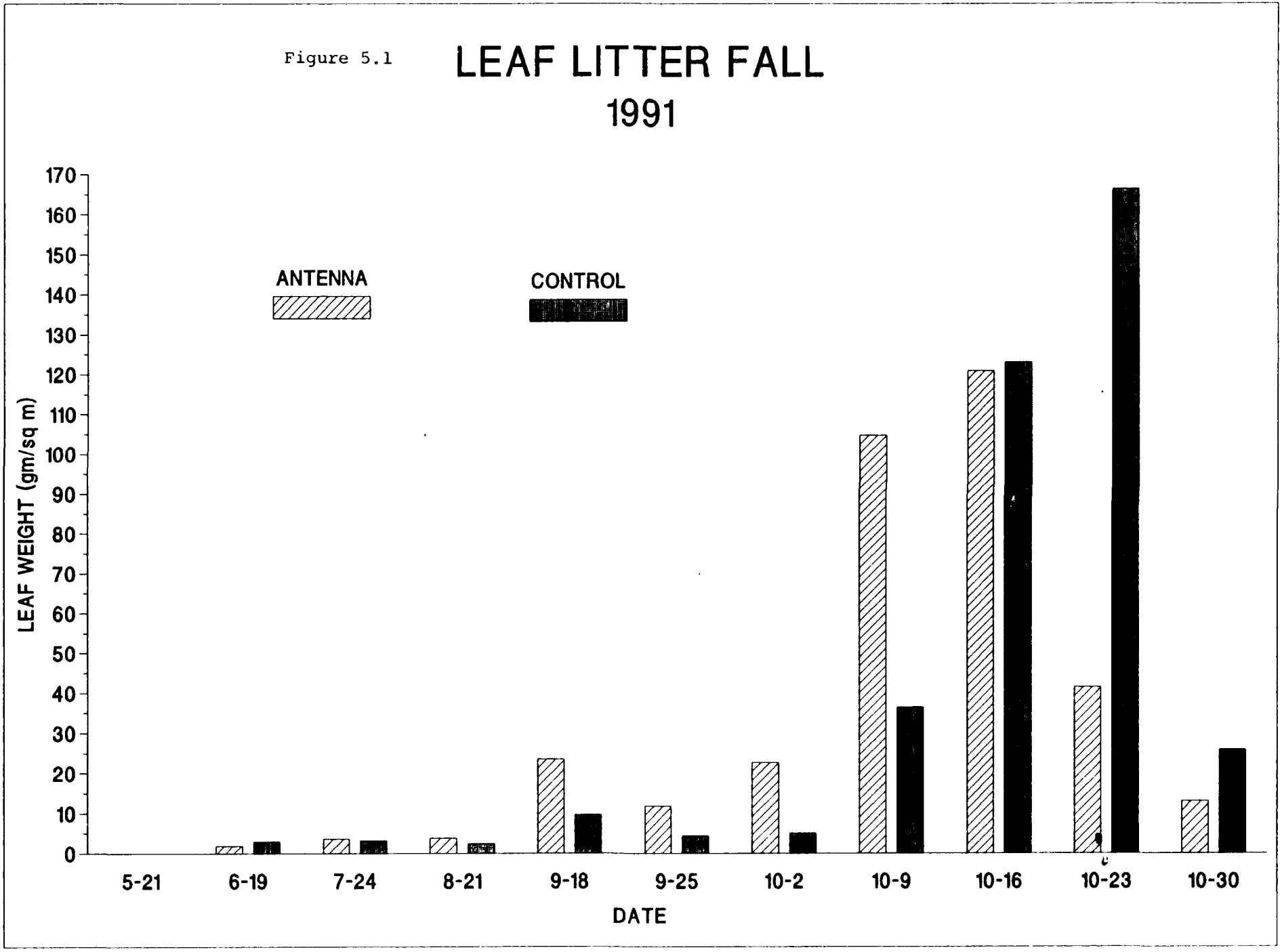

LEAF LITTER FALL
1991
ANTENNA
CONTROL
LEAF WEIGHT (gm/sq m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
5-21
6-19
7-24
8-21
9-18
9-25
10-2
10-9
10-16
10-23
10-30
DATE

Figure 5.2a CUMULATIVE LEAF FALL
ANTENNA SITE
1984 - 1991

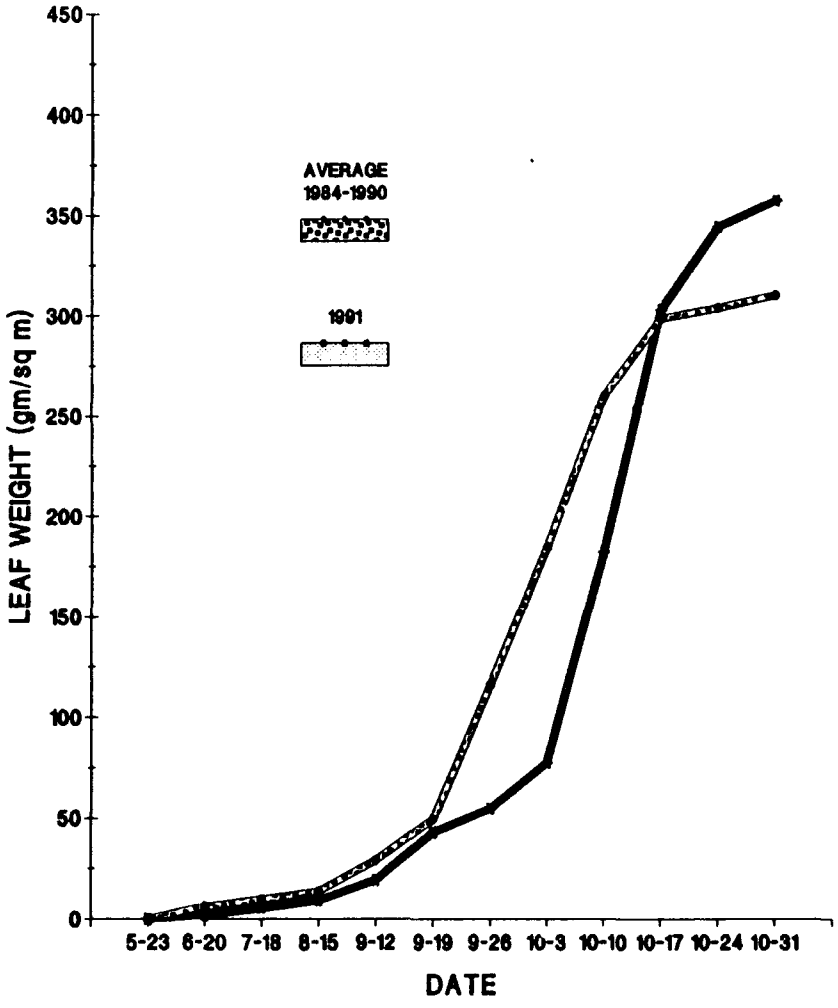


Figure 5.2b CUMULATIVE LEAF FALL
CONTROL SITE
1984 - 1991

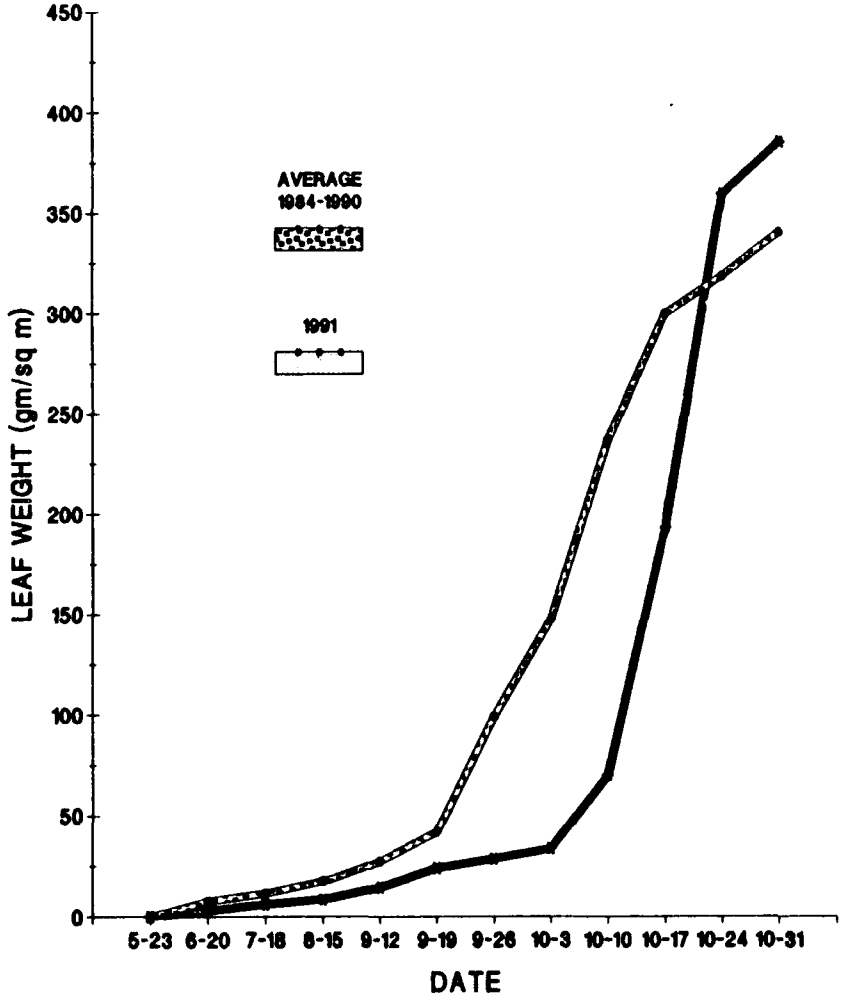


Table 5.1. ANOVA table for the analysis of litter components and foliar nutrients

Source of Variation	df	SS	MS	F
Plot	2	SS_P	MS_P	
$MS_P/MS_{E(S)}$				
Site	1	SS_S	MS_S	
$MS_Y/MS_{E(S)}$				
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	# years	SS_Y	MS_Y	
$MS_Y/MS_{E(Y)}$				
Site x year	(1)(#yrs-1)	SS_{SXY}		MS_{SXY}
$MS_{SXY}/MS_{E(Y)}$				

would adequately represent the distribution of red oak on each site. Three trees of each diameter were located adjacent to the permanent measurement plots at each site to minimize disturbance. Leaf samples were obtained from near the top of the crown using a 12 gauge shotgun with a full choke.

All litter and foliage samples were dried at 60°C in a forced draft oven. The litter was separated into leaves, wood, and miscellaneous categories and weighed. Leaf litter from a 0.25 m^2 compartment in each trap was separated by tree species. A representative subsample of ten leaves was taken from each foliage collection and weighed. All samples were ground to pass a 40 mesh sieve for subsequent N, P, K Ca and Mg analysis.

Progress

Litter weight

In 1991, the major litter fall in the ELF study area started between October 2 and October 9 and was completed by November 1 on both the antenna and control sites (Figure 5.1). Based on the previous 7-year average, this litter fall period began at a later date and continued longer into October (Figure 5.2a&b). As in past years, periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall. These differences in weekly leaf fall were related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control site (Table 5.2). Conversely, the control site has much higher numbers of northern red oak. Oak leaves remain on the trees longer than either maple or

Table 5.2. Leaf litter fall by tree species at the antenna and control sites: 1985-1990.

Tree Species	Leaf Weight (g/m^2) 1985	1986	1987	1988	1989	1990	1991	% of Total 1985-1990	% of Total 1991
Antenna									
Red Maple	135	147	142	143	127	103	129	43	37
Red Oak	93	120	105	116	95	71	132	32	38
B. Aspen	45	52	46	56	18	32	59	14	17
Q. Aspen	1	1	2	3	2	1	3	<1	1
P. Birch	25	21	25	28	28	24	21	8	6
Red Pine	1	1	2	2	2	1	1	<1	<1
Control									
Red Maple	42	55	47	41	48	41	49	15	13
Red Oak	227	266	208	230	223	184	293	70	78
B. Aspen	14	17	13	12	16	17	16	5	5
Q. Aspen	11	9	8	13	10	3	7	3	2
P. Birch	19	22	26	26	20	13	9	7	2
Red Pine	0	0	0	0	0	0	0	0	0

aspen, and account for much of the litter fall variations between locations.

The weight of the litterfall leaf component on both the antenna and control site in 1991 was the second highest of the eight years measured (Table 5.3). This reverses the trend in annual litter weights reductions which have occurred since 1986. While strong yearly litterfall fluctuations were evident on these sites, analysis of variance (ANOVA) using the seven year litterfall results showed no significant site or site x year interactions between the three litter components. Covariate analysis using stand and environmental variables that affect stand production rates was used to reduce litter fall variability among years, and improve detection limits between the antenna and control site. Similar to past years, soil and air temperature generally showed the highest correlations with litter production and gave the best results when used in the analyses of covariance (Table 5.4). The use of these covariates reduced variability in litter fall among years and lowered the P values between sites (Table 5.5).

Results of these data analyses have shown that all three litter components could be used to determine the effects of ELF fields on forest stands. However, the **a priori** detection limits for differences in foliage litter among years and between sites are much lower than with the wood and the miscellaneous litter fraction (Table 5.6), and so would be a more sensitive indicator of possible ELF effects. Given these limits and the results of the analysis of covariance, the lack of significance between the antenna and control sites for all three litter components indicate that the operational use of the ELF antenna in 1991 had no detectable effects on tree litter production.

Litter Nutrient Content

Total amounts of nutrients returned to the soil on each site reflect differences in both litter weight and nutrient concentrations (Table 5.7). Average nutrient concentrations of the various litter components and for individual tree species showed considerable variability between the two sites, but none were significantly different (Table 5.8 and 5.9). Covariate analysis using site and ambient factors listed in Table 5.10 was used to try and remove differences in litter nutrient concentrations among sites and years. As was noted in last year's report, significant site x year interactions for some litter components, either composited or for individual tree species, could not be removed by covariate analyses (Tables 5.11 and 5.12). Multiple range tests (SNK) were performed on these adjusted means to evaluate whether nutrient concentrations had changed in response to ELF antenna operation starting in 1987. These results showed that in all cases significant litter nutrient concentration differences existed between sites and years prior to the antenna operation.

Table 5.3. Total litter fall at the antenna and control sites: 1984-1991

	Antenna	Control
	g/m^2	
Leaves		
1984	307 (66)	357 (102)
1985	347 (57)	352 (27)
1986	351 (49)	412 (87)
1987	332 (32)	319 (34)
1988	326 (45)	353 (53)
1989	305 (39)	344 (49)
1990	238 (25)	274 (38)
1991	348 (34)	379 (44)
Average	319	348
Wood		
1984	44 (32)	54 (26)
1985	55 (31)	64 (33)
1986	43 (30)	58 (43)
1987	57 (38)	76 (38)
1988	53 (34)	62 (33)
1989	46 (40)	44 (33)
1990	57 (39)	88 (56)
1991	43 (36)	54 (70)
Average	50	63
Miscellaneous		
1984	34 (24)	27 (14)
1985	52 (33)	45 (15)
1986	32 (8)	29 (11)
1987	33 (14)	28 (14)
1988	94 (64)	80 (35)
1989	97 (73)	64 (24)
1990	52 (16)	75 (23)
1991	30 (12)	25 (7)
Average	54	43

Collection Period:

1984 - June 20, 1984 - Oct. 24, 1984
1985 - Oct. 25, 1984 - Oct. 23, 1985
1986 - Oct. 24, 1985 - Oct. 22, 1986
1987 - Oct. 23, 1986 - Oct. 21, 1987
1988 - Oct. 22, 1987 - Nov. 3, 1988
1989 - Nov. 4, 1988 - Nov. 1, 1989
1990 - Nov. 2, 1989 - Oct. 31, 1990
1991 - Nov. 1, 1990 - Oct. 30, 1991

Numbers in parentheses are standard deviations.

Table 5.4. Correlations between litter component weight and the covariates selected for inclusion in the analysis of covariance: 1990-1991

	Litter Component*		
Covariate	Foliage	Wood	Miscellaneous
Soil Temperature at 10 cm (April 1 - July 15)	--	---	-.48
Air Temperature Degree Days (August 16-September 15)	-.27	--	--

* Significant at the p=0.05 level

Table 5.5 Significance levels from the split plot analysis of covariance for litter components: 1985 - 1991

Factor	Foliage	Wood	Miscellaneous
	----------p values----------		
Site	0.916	0.121	0.162
Years	0.000	0.112	0.000
Site x Years	0.096	0.788	0.165

Table 5.6. Detection limits of litter component weights between treatment sites and between years.*

Litter Component	Sites		Years	
	g/m^2	%	g/m^2	%
Foliage	58.8	17.6	24.1	7.2
Wood	18.5	32.4	20.7	36.3
Miscellaneous	23.8	45.2	17.9	34.0

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

To further investigate these significant site x year interactions, covariate analyses were run using both environmental measurements and the ELF field exposure data for 1989 and 1990 (Appendix A). The inclusion of the various ELF field values did not alter or remove the site x year interactions found for litter nutrient concentrations. Since leaf litter nutrient concentration detection levels are generally below fifteen percent of the mean (Tables 5.13 and 5.14), these results indicate that differences in litter nutrient concentrations between the antenna and the control site can not be attributed to the low level ELF fields generated since 1987.

Red Oak Foliage Analyses

Nutrient concentrations in red oak foliage show considerable variability between the antenna and the control sites, but these generally reflect the nutrient status of the two sites before antenna transmissions began (Table 5.15). Results from covariate analyses using soil and climatic data showed there were significant site x year interactions for N, K, and Ca that could not be explained using the covariates tested (Table 5.16). Similar results were found for site x month interactions. Multiple range tests were used to evaluate these site differences. Similar to the litterfall results, these analyses showed that significant site x year and site x month differences occurred prior to the antenna operation beginning in 1987.

Table 5.7. Average nutrient content of litterfall at the antenna and control sites: 1985-1990

	Antenna		Control	
	1985-1989 (Average)	1990	1985-1989 (Average)	1990
	(kg/ha)			
Foliage				
N	23.1	18.7	22.9	22.4
P	4.7	4.2	5.9	7.5
K	10.7	8.9	14.7	11.6
Ca	35.0	27.6	37.7	33.0
Mg	5.8	4.8	6.1	4.9
Wood				
N	2.3	2.4	2.1	4.6
P	0.3	0.3	0.3	0.5
K	0.5	0.7	0.8	1.2
Ca	4.9	5.2	7.3	8.9
Mg	0.3	0.3	0.4	0.6
Miscellaneous				
N	8.5	5.8	11.4	7.9
P	1.0	0.7	0.7	1.4
K	3.3	1.5	2.7	3.8
Ca	4.3	5.2	5.0	4.0
Mg	0.7	0.4	0.5	0.5
Total				
N	33.9	26.9	29.5	34.9
P	5.9	5.2	7.0	9.4
K	14.6	11.1	17.7	16.6
Ca	44.2	36.3	50.0	45.9
Mg	6.8	5.5	7.0	6.0

Values in rows denoted by different letters are significantly different at the p=0.05 level.

Table 5.8. Average nutrient concentrations of litter components on the antenna and control sites: 1985-1990

	Antenna	Control
	(%)	
Foliage		
N	0.72 (0.14)	0.69 (0.11)
P	0.15 (0.03)	0.19 (0.08)
K	0.34 (0.08)	0.42 (0.08)
Ca	1.08 (0.14)	1.11 (0.14)
Mg	0.19 (0.03)	0.18 (0.01)
Wood		
N	0.46 (0.13)	0.49 (0.13)
P	0.05 (0.01)	0.06 (0.01)
K	0.11 (0.04)	0.12 (0.05)
Ca	0.96 (0.23)	1.20 (0.29)
Mg	0.06 (0.01)	0.07 (0.01)
Miscellaneous		
N	1.15 (0.27)	1.02 (0.20)
P	0.13 (0.03)	0.14 (0.05)
K	0.41 (0.16)	0.42 (0.19)
Ca	0.60 (0.21)	0.82 (0.43)
Mg	0.09 (0.02)	0.08 (0.01)

Numbers in parentheses are standard deviations.

Table 5.9. Average nutrient concentrations of tree litter on the antenna and control sites: 1985-1990

	Antenna	Control
	(%)	
Northern Red Oak		
N	0.72 (0.19)	0.65 (0.09)
P	0.13 (0.02)	0.18 (0.09)
K	0.33 (0.07)	0.40 (0.06)
Ca	0.98 (0.10)	1.03 (0.12)
Mg	0.12 (0.01)	0.15 (0.02)
Paper Birch		
N	0.80 (0.13)	0.79 (0.09)
P	0.17 (0.05)	0.18 (0.03)
K	0.42 (0.08)	0.57 (0.14)
Ca	1.41 (0.23)	1.18 (0.20)
Mg	0.28 (0.03)	0.28 (0.03)
Big Toothed Aspen		
N	0.82 (0.12)	0.71 (0.14)
P	0.13 (0.06)	0.16 (0.05)
K	0.36 (0.12)	0.49 (0.11)
Ca	1.30 (0.20)	1.46 (0.19)
Mg	0.26 (0.03)	0.22 (0.03)
Red Maple		
N	0.46 (0.06)	0.48 (0.11)
P	0.17 (0.04)	0.18 (0.03)
K	0.25 (0.09)	0.34 (0.09)
Ca	1.07 (0.11)	1.19 (0.11)
Mg	0.19 (0.02)	0.20 (0.02)

Numbers in parentheses are standard deviations.

Table 5.10. Covariates used in covariate analyses of litter nutrient concentrations among sites and year.

Soil Nutrients in September	
Soil N	a
Soil P	b
Soil K	c
Soil Ca	d
Soil Mg	e
Air temperature degree days	
in September	f
in October	g
Air temperature degree days running total	
to the end of September	h
to the end of October	i
Air temperature	
in September	j
in October	k
Soil temperature at 5 cm	
in September	l
in October	m
Soil temperature at 10 cm	
in September	n
in October	o
Soil temperature degree days at 5 cm running total	
to the end of September	p
to the end of October	q
Soil temperature degree days at 10 cm	
in September	r
in October	s
Soil temperature degree days at 5 cm	
in September	t
in October	u

Table 5.11. Results of covariate analyses of site and year differences in litter component nutrient concentration: 1985-1990

	N	P	K	Ca	Mg
	p value				
Leaf	--	(c)*	--	(f)	(e)
Site	.335	.084	.094	.238	.021
Year	.044	.001	.000	.000	.000
Year x Site	.413	.003	.273	.845	.079
Wood	(ps)	(s)	(c)	(d)	(c)
Site	.923	.974	.312	.141	.026
Year	.000	.308	.001	.006	.065
Year x Site	.807	.725	.939	.105	.356
Miscellaneous	(cq)	(bc)	(h)	(dn)	(am)
Site	.860	.551	.222	.260	.416
Year	.134	.000	.000	.000	.055
Year x Site	.021	.003	.002	.002	.065

*Variables used in COANOVA (see Table 5.10).

Table 5.12. Results of covariate analyses of site and year differences in leaflitter nutrient concentrations by species: 1985-1990*

	N	P	K	Ca	Mg
	p value				
Northern Red Oak	--	(cf)	(cf)	(bh)	(ei)
Site	.2287	.420	.004	.910	.765
Year	.003	.005	.002	.000	.000
Year x Site	.701	.009	.848	.018.	.005
Hazelnut and Paper Birch	(ab)	(cf)	(ah)	(kh)	(ah)
Site	.880	.575	.901	.647	.882
Year	.000	.053	.000	.000	.035
Year x Site	.616	.058	.005	.069	.079
Big Toothed Aspen	(bq)	(cde)	(dg)	(der)	(cdg)
Site	.091	.882	.114	.047	.268
Year	.000	.000	.031	.001	.000
Year x Site	.000	.016	.151	.131	.013
Red Maple	(cgh)	(l)	(ci)	(hit)	--
Site	.939	.495	.560	.913	.304
Year	.000	.000	.000	.006	.000
Year x Site	.086	.001	.064	.129	.300

*Variables used in COANOVA (see Table 5.10.).

Table 5.13. Detection limits for litter nutrient concentrations by component: 1985-1990*

Component	Site		Year	
	ppm	% of mean	ppm	% of mean
Leaf				
Ca	574	5.2	423	3.8
Mg	69	3.8	47	2.6
K	382	10.0	165	4.3
N	294	4.2	435	6.2
P	142	8.4	173	10.3
Wood				
Ca	775	7.2	800	7.4
Mg	29	4.4	46	7.2
K	124	9.8	135	10.7
N	294	6.2	405	8.5
P	54	9.7	55	9.8
Misc.				
Ca	490	6.9	652	9.2
Mg	87	9.9	38	4.3
K	254	6.2	282	6.8
N	990	9.1	714	6.5
P	97	7.2	92	6.8

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Table 5.14. Detection limits for leaf litter nutrient concentrations by species: 1985-1990*

Species	Site		Year	
	ppm	% of mean	ppm	% of mean
Northern Red Oak				
Ca	293	2.9	143	1.4
Mg	162	11.9	30	2.2
K	88	2.4	148	4.1
N	468	6.8	437	6.4
P	236	15.0	163	10.3
Hazelnut and Birch				
Ca	1072	13.1	329	2.5
Mg	433	15.8	82	2.9
K	218	4.4	215	4.4
N	622	7.8	252	3.2
P	232	13.1	131	6.8
Big Tooth Aspen				
Ca	1409	9.7	287	2.1
Mg	340	14.3	78	3.3
K	491	11.5	276	6.4
N	477	6.2	233	3.1
P	280	19.5	145	10.1
Red Maple				
Ca	1175	10.4	239	2.1
Mg	92	4.7	44	2.2
K	254	8.6	142	4.8
N	641	13.5	171	3.6
P	112	6.4	72	4.1

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Table 5.15. Northern Red Oak foliage nutrient concentration for antenna and control sites: 1985 to 1990

	Antenna		Control	
	1985-1989	1990	1985-1989	1990
	(%)		(%)	
N	1.95	2.60	1.97	2.48
P	0.21	0.22	0.21	0.21
K	0.86	0.92	1.00	0.99
Ca	0.71	0.76	0.72	0.67
Mg	0.15	0.15	0.15	0.16

A factor in evaluating foliage nutrient concentrations is the weight of individual leaves. Consequently, an analysis of variance was conducted on average yearly leaf weights on the antenna and the control sites (Table 5.17) No significant site, month, year, and diameter interactions were found.

Since good covariates are presently lacking for the covariate analysis of foliage nutrient content, detection limits were relatively high (Table 5.18). Detection limits were mostly under five percent for yearly differences, but generally higher between sites and year x sites. Thus, changes in tree nutrient translocation and cycling as affected by the ELF electromagnetic fields need to be relatively large to be detected by these analyses.

Table 5.16. Results of covariate analyses for differences in foliage nutrient concentration: 1985-1990

	N (1)*	P (2)	K (3)	Ca (4)	Mg (5)
	p values				
Site	.993	.370	.001	.924	.559
Tree Diameter	.253	.112	.079	.321	.064
Site x Diameter	.709	.035	.567	.097	.109
Year	.000	.000	.000	.000	.000
Year x Site	.000	.186	.000	.003	.318
Year x Diameter	.506	.757	.005	.231	.310
Year x Site x Diameter	.285	.012	.065	.121	.277
Month	.000	.000	.000	.000	.000
Month x Site	.068	.076	.230	.015	.922
Month x Year	.000	.000	.000	.000	.000
Month x Year x Site	.148	.001	.000	.125	.058

* Covariates used

[1] Average maximum air temperature, soil moisture at 10 cm, soil temperature degree days at 10 cm - running total
[2] Air temperature degree days
[3] Soil K and Mg, soil temperature degree days at 10 cm
[4] Soil temperature degree days at 10 cm - running total
[5] Average maximum air temperature, soil moisture at 5 cm, soil temperature degree days at 5 cm

Table 5.17. Analysis of variance results testing for differences in the average weight of ten leaf samples by site, tree diameter and sampling time (1985-91).

	p value
Site	.914
Diameter	.592
Site x Diameter	.207
Year	.000
Year x Site	.601
Year x Diameter	.550
Year x Diameter x Site	.160
Month	.002
Month x Site	.048
Month x Year	.070
Month x Year x Site	.161

Table 5.18. Detection limits for Northern Red Oak foliage nutrient concentrations: 1985-1990*

	Site		Year		Year x site	
	ppm	% of mean	ppm	% of mean	ppm	% of mean
N	1143	5.6	817	4.0	1156	5.6
P	101	4.8	187	8.8	265	12.5
K	577	6.4	417	4.6	590	6.5
Ca	783	10.9	360	5.0	509	7.1
Mg	161	10.7	73	4.9	104	6.9

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

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Appendix A

EM Field Measures

Each year, IITRI has taken measurements of 60 and 76 Hz transverse, longitudinal, and magnetic fields on each of the study plots at the ground, antenna, and control sites (see attached report). Interpolation equations have been developed in past years to estimate the average EM field exposure levels for specific locations within the study plots (Mroz et al. 1990). These equations were used to calculate an average exposure level for each plot (Table 1A-E). In 1990, it was found that the 76 Hz magnetic flux measurements were not significantly different from those in 1989 and the two years were combined, resulting in the equations described in the attached memorandum.

In 1990, IITRI found that the patterns of the longitudinal field measurements were very complex and that the equations developed for use in this project in previous years were inadequate. IITRI provided digital data incorporating site maps and longitudinal field exposure contours for the antenna and the ground sites. As a result of discussions between IITRI and MTU personnel, it was decided that the best way to estimate longitudinal field exposures was to utilize the contour lines developed by IITRI in 1990 and to scale the values from year to year according to the average longitudinal field exposure measurements for a plot. These procedures were used to estimate the mean exposure levels in Table 1. Unfortunately, these analyses were not completed in time for the longitudinal field exposure levels to be completely incorporated into the 1990 analyses for all elements.

The magnetic flux information, therefore, is incorporated into the 1990 analyses and the longitudinal field information will be incorporated into the analyses in the near future. Further discussions will be held with IITRI personnel in the next year identify the best methods of incorporating the transverse field information into the analyses.

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799

312/567-4000

5 February 1991

Dr. Glenn Mroz
Department of Forestry
Michigan Technical University
Houghton, MI 49931

Dear Dr. Mroz:

The purpose of this letter is to provide you with documentation of the 1990 ELF electromagnetic (EM) field measurements made by IITRI at your study sites. The 1990 measurement activities were as follows:

1) EM fields were measured at all historic locations.

2) Extensive longitudinal electric field surveys were performed at treatment sites to identify spatial field variations (field contours).

3) Fixed longitudinal electric field probes were established at treatment sites to study temporal field variations.

Preliminary data from the electric field surveys and fixed probe measurements were presented in our letter of 6 September 1990. Further review, reformatting, and in some cases, additions to these data have been made since then. The updated versions are included in this letter.

Historic Measurements

Measurement Sites

Complete sets of EM measurements were made at 50 locations at the study sites listed in Table 1. Measurement positions within each study site are diagrammed in Figures 1-5. All measurement points characterized in 1986 through 1989 were remeasured in 1990. In addition, 5 measurement points were added at your antenna study site (4T2-26, 33-36) to establish a measurement profile across the pole stand and herbaceous reserve.

COMMITMENT TO EXCELLENCE

EM Measurement Protocol

Measurements of 76 Hz EM fields were conducted in 1990 during operation of both antennas with 150 ampere currents. Because of the distance of the pine needle and red maple leaf sample collection points from the antennas, 76 Hz fields there are below the sensitivity of our measurement equipment and were therefore not measured. Ambient 60 Hz EM fields were measured only at the control site and all 3 sample collection points. It was not possible to measure ambient 60 Hz EM fields at the antenna or ground sites because the antennas were operating with a modulated signal, and the EM fields generated under these conditions swamp out the lower level 60 Hz fields.

Three types of EM fields were characterized at each measurement point: transverse (or air) electric field, longitudinal (or earth) electric field, and magnetic flux density. For each of the fields, a set of orthogonal measurements were made and reduced to a single magnitude by vector addition. The EM field intensity measurement conditions are summarized below:

1) Ambient 60 Hz fields were measured at the control study site and sample collection points with both antennas operating at 150 amperes, standard phasing, and a modulated signal.

2) Ambient 60 Hz fields could not be measured at the treatment study sites in 1990 because the antenna operated with a modulated signal.

3) 76 Hz fields generated by the NRTF-Republic were measured with both antennas operating at 150 amperes, standard phasing, and a modulated signal.

60 Hz EM Fields

60 Hz EM field measurement data for 1984 through 1990 are presented in Tables 2-4. The 60 Hz ambient field intensities measured at your control and sample collection sites in 1990 are consistent with values measured in previous years.

76 Hz EM Exposures - 1990

The 76 Hz EM field measurement data from the 1990 annual EM survey, along with data from earlier years, are presented in Tables 5-7. All field measurements were made and are presented as vector sum magnitudes. The antenna currents at which measurements were made in each year are given in the column headings of the tables. The annual increases in field magnitudes reflect the level of antenna current at the time of measurement: 4 or 6 amperes in 1986, 15 amperes in 1987, 75 amperes in 1988, and 150 amperes in 1989 and

1990. The 1990 measurements are consistent with the 1989 measurements at the same current, and proportional to the 1986, 1987 and 1988 measurements made at lower currents.

Several historic measurement points at the treatment study sites have been selected along transects perpendicular to the antenna and ground ROW's to facilitate the plotting of EM field profiles across these sites. Profiles of the 76 Hz transverse electric field, magnetic flux density, and longitudinal electric field for 1989 and 1990 appear in Figures 6-9. The historic measurement points which comprise each profile are identified in these figures. Measurement points 4T2-26 and 33 through 36 were not established in 1989 and this profile is therefore missing for that year.

The transverse electric fields in the pine plantations at both the antenna and ground sites decrease in a uniform fashion with increasing distance from the antenna or ground feed wire. The 1990 fields are slightly less than those measured in 1989, which is likely the effect of increased shielding by the growing pine trees. At the ground site there is a dip in the field profiles near the plot center, which appears in both 1989 and 1990. This is caused by an interaction and cancellation of fields produced by the overhead and buried ground wires. These profiles may be used to estimate the transverse electric field intensity at any point in the pine plantations by graphical interpolation, given the distance of the point from the antenna or ground wires.

The transverse electric field profile for the pole stand and herbaceous reserve plots is not as uniform as that for the pine plantations. The electric field, normally set up by the potential difference between the antenna wire and the earth, is shielded by the tall trees at these plots. The air electric fields which do appear at these plots are the byproduct of the longitudinal (earth) electric field which creates potential differences between the trees. The air field profiles for these plots are therefore subject to the same variables which affect the longitudinal electric field as is shown by similarities in the profiles for these two fields. The longitudinal electric fields vary significantly and unpredictably across the pole stand and herbaceous reserve plots as discussed in following paragraphs. The transverse electric field at other points on these plots should therefore not be estimated using the historic profile data.

The magnetic flux density is dependent only on the distance of the measurement point from the source. The profiles for this field are therefore the most predictable and stable of those measured, decreasing uniformly with increasing distance from their sources. At the ground site, a dip in the magnetic flux density profile near the plot center, similar to that seen for the transverse electric field, appears in both 1989 and 1990. This again, is due to an

interaction and cancellation of fields generated by the overhead and buried ground wires. These profiles may be used to estimate the magnetic flux density at any point at your treatment sites with very good accuracy.

The longitudinal electric field at your treatment sites is influenced by several factors, making it very difficult to predict. At your antenna site the field shows both increases and decreases with increasing distance from the antenna. Such irregularities are the result of varying terrain elevations and differences in soil conductivity.

The longitudinal electric field at your ground site has a null over the buried ground wire, with relatively high peaks on both sides of the wire. This is characteristic of the earth electric field near an ELF ground wire. The field at the ground site falls off much more uniformly than at the antenna site, indicating that the soil conductivity is much more uniform here.

Because the longitudinal electric field behaves unpredictably across your treatment sites, it is not recommended that the historic profile data be used for field estimates at other points at these sites. Use of the historic data should be limited to year-to-year comparisons and for bracketing of field exposures.

Longitudinal E-Field Survey

Extensive longitudinal electric field surveys were conducted to characterize the complex spatial field variations at the antenna and ground sites. These surveys consisted of a closely spaced grid of measurements from which electric field contours could be determined. Measurements were also taken near monitoring equipment where high field gradients were expected. The locations of the grid measurement points are mapped in Figures 10 and 11. Measured field intensity values are given at each point. EM field profiles similar to those in Figures 6-9 were drawn for each row and column of the grid. Graphical interpolation was then used to locate points of constant electric field intensity and to produce two dimensional contour drawings of the longitudinal electric field. The antenna and ground site contours are presented in Figures 12 and 13.

Both the field survey and contour drawings show the locations of the ambient monitoring sensors. The sensors, as can be clearly seen from the contour maps, are surrounded by regions of high field intensities and field gradients. These are the result of ELF currents coupled to the sensor cable sheaths and grounding system installed for lightning protection. The maximum field intensities at the antenna site sensors are about twice the level of those at the ground site sensors because of differences in coupling at the two sites.

Coupling levels are higher at the antenna site because the antenna currents are considerably larger than those in either the overhead or buried ground wires. Also, the orientation of the ground site sensor cables to the ground wires make them less susceptible to field coupling than those at the antenna site.

Accurate estimations of the longitudinal electric field intensity at any point on your antenna and ground study sites can be made using the contour maps in Figures 12 and 13. Software copies (.DXF files) of these contour drawings are enclosed, to aid in your data analysis, as per your request. Please inform us if there is any trouble in reading the information in these files.

Fixed Longitudinal E-Field Probes

The contour drawings in Figures 12 and 13 provide for the most accurate longitudinal electric field estimates at your treatment study sites. They do not, however, provide information on the temporal variation of the field intensities. For this reason, fixed probes were established at several measurement point locations at your antenna and ground study sites. The fixed probe locations are shown together with the historic measurement points in Figures 1 and 2. Some of these measurement locations are common with historic measurement point locations, while the others are unique. The fixed probe measurement points are identified in Tables 8 and 9, which list measurement data taken from late June 1990 through January 1991. Fixed probe measurements are taken twice a month, with the expectation of identifying long term, or seasonal variations at these points. With few exceptions, the fields at the fixed probes have shown no significant variations. Exceptions occurred at points 4T4-4 and 9, where the field intensities dropped significantly in October and have remained at this lower level. The reason for this reduction is not evident, but a bad connection or poor soil-electrode contact is expected. The field intensity measured at point 4T2-25 on 10 July 90 is about one half the magnitude of all other measurements at this point and a bad soil-electrode contact is also suspected. Poor soil-electrode contact can occur if the probe is bumped and bent over or partially pulled out of the ground.

The fixed probe measurements provide a good overview of the variations in the longitudinal electric field at your treatment study sites over long time periods. A more thorough study of longitudinal electric field temporal variations, using data loggers, may be implemented in 1991. Such loggers would make hourly measurements of the longitudinal electric field at selected measurement points to provide information on daily as well as long term field variations.

NRTF-Republic Operations - 1990

The NRTF-Republic typically operated continuously and at full power during 1990. Regular exceptions to this were scheduled weekly maintenance periods lasting for about 5 hours on Tuesdays and Thursdays. Detailed summaries of the antenna operating conditions are being prepared and will be presented in the annual report documenting EM field measurements and engineering support for the Ecological Monitoring Program in 1990. These summaries, together with the EM field measurements described can be used to calculate cumulative exposure levels.

1991 Schedule

As an operational communications system, the NRTF-Republic is expected to continue full-time 150 ampere operation except during scheduled maintenance periods. The annual EM measurements for 1991 have not been scheduled, but are likely to be in the June-October period. If you require any special engineering assistance or EM measurements in addition to those normally conducted or already discussed above, please inform us immediately so that these activities may be scheduled.

Sincerely,
IIT RESEARCH INSTITUTE

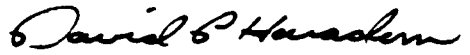

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TABLE 1. SITE NO. CROSS-REFERENCE
Upland Flora and Soil Microflora Studies

IITRI Site No.	Investigator's Site Name	Location		
		Township	Range	Section(s)
4T2	Martell's Lake (Overhead): ML	T45N	R29W	28
4T4	Martell's Lake (Buried): EP	T45N	R29W	28
4C1	Paint Pond Road Control	T41N	R32W	3
4S1	Red Maple Leaf Collection	T55N	R35W	21
4S2	Oak Leaf Collection	T41N	R32W	3
4S3	Pine Needle Collection	T54N	R34W	5

TABLE 2. 60 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	(a) 1983	(a) 1984	(a) 1985	(b) 1986	(c) 1987	(c) 1988	(d) 1989	(d) 1990
4C1-6	-	0.003	<	<	<	<	<	<
4C1-7	-	0.006	<	<	<	<	<	<
4C1-8	-	0.004	<	<	<	<	<	<
4C1-9	-	0.002	<	<	<	<	<	.
4C1-10	-	-	<	<	<	<	<	<
4C1-11	-	-	<	<	<	<	<	<
4C1-12	-	-	<	<	<	<	<	<
4C1-13	-	-	<	<	<	<	<	<
4T2-3	-	0.001	<	<	<	0.002	#	#
4T2-4	-	-	<	<	<	0.001	#	#
4T2-5	-	-	<	<	<	0.011	#	#
4T2-6	-	-	<	<	<	<0.001	#	#
4T2-7	-	-	<	<	<	<0.001	#	#
4T2-8	-	-	<	<	<	/	#	#
4T2-9	-	-	<	<	<	<	#	#
4T2-10	-	-	<	<	<	<	#	#
4T2-11	-	-	<	<	<	<	#	#
4T2-12	-	-	<	<	<	/	#	#
4T2-13	-	-	<	<	<	<0.001	#	#
4T2-14	-	-	<	<	<	0.011	#	#
4T2-15	-	-	-	-	-	-	#	#
4T2-16	-	-	-	-	-	-	#	#
4T2-17	-	-	-	-	-	-	#	#
4T2-18	-	-	-	-	-	-	#	#
4T2-19	-	-	-	-	-	-	#	#
4T2-26	-	-	-	-	-	-	-	#
4T2-33	-	-	-	-	-	-	-	#
4T2-34	-	-	-	-	-	-	-	#
4T2-35	-	-	-	-	-	-	-	#
4T2-36	-	-	-	-	-	-	-	#

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.
< = measurement est. <0.001 V/m based on earth E-field.

TABLE 2. 60 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1983 (a)	1984 (a)	1985 (a)	1986 (b)	1987 (c)	1988 (c)	1989 (d)	1990 (d)
4T4-4	-	0.003	<	<	<0.001	<0.001	#	#
4T4-5	-	-	<	<	0.006	0.003	#	#
4T4-6	-	-	<	<	<	<	#	#
4T4-7	-	-	<	<	<	<	#	#
4T4-8	-	-	<	<	<	<	#	#
4T4-9	-	-	<	<	<	<	#	#
4T4-10	-	-	<	<	<	<	#	#
4T4-11	-	-	<	<	0.010	0.009	#	#
4T4-12	-	-	-	<	0.005	0.007	#	#
4T4-13	-	-	-	-	-	-	#	#
4T4-14	-	-	-	-	-	-	#	#
4T4-15	-	-	-	-	-	-	#	#
4T4-16	-	-	-	-	-	-	#	#
4T4-17	-	-	-	-	-	-	#	#
4T4-18	-	-	-	-	-	-	#	#
4T4-19	-	-	-	-	-	-	#	#
4T4-20	-	-	-	-	-	-	#	#
4S1-1	-	-	-	-	0.013	0.033	0.011	0.017
4S2-1	-	-	-	-	<	<	<	<
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.
< = measurement est. <0.001 V/m based on earth E-field.

TABLE 3. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1983 (a)	1984 (a)	1985 (a)	1986 (b)	1987 (c)	1988 (c)	1989 (d)	1990 (d)
4C1-6	-	0.022	0.016	0.005	0.043	0.023	0.016	0.024
4C1-7	-	0.143	0.123	0.077	0.178	0.118	0.030	0.039
4C1-8	-	0.104	0.117	0.077	0.131	0.078	0.018	0.063
4C1-9	-	0.011	0.019	0.024	0.034	0.032	0.023	0.023
4C1-10	-	-	0.090	0.068	0.118	0.106	0.054	0.041
4C1-11	-	-	0.160	0.107	0.132	0.146	0.066	0.068
4C1-12	-	-	0.104	0.101	0.075	0.093	0.042	0.042
4C1-13	-	-	0.040	0.030	0.046	0.065	0.025	0.039
4T2-3	-	0.51	0.39	0.194	0.27	0.28	#	#
4T2-4	-	-	0.27	0.24	0.30	0.25	#	#
4T2-5	-	-	0.43	0.32	0.20	0.20	#	#
4T2-6	-	-	0.66	0.46	0.192	0.22	#	#
4T2-7	-	-	0.42	0.52	0.197	0.28	#	#
4T2-8	-	-	0.47	0.190	0.22	/	#	#
4T2-9	-	-	0.49	0.31	0.183	0.25	#	#
4T2-10	-	-	0.44	0.32	0.155	0.166	#	#
4T2-11	-	-	0.51	0.40	0.31	0.43	#	#
4T2-12	-	-	0.47	0.38	0.24	/	#	#
4T2-13	-	-	0.76	0.31	0.31	0.25	#	#
4T2-14	-	-	0.61	0.29	0.35	0.21	#	#
4T2-15	-	-	-	-	-	-	#	#
4T2-16	-	-	-	-	-	-	#	#
4T2-17	-	-	-	-	-	-	#	#
4T2-18	-	-	-	-	-	-	#	#
4T2-19	-	-	-	-	-	-	#	#
4T2-26	-	-	-	-	-	-	-	#
4T2-33	-	-	-	-	-	-	-	#
4T2-34	-	-	-	-	-	-	-	#
4T2-35	-	-	-	-	-	-	-	#
4T2-36	-	-	-	-	-	-	-	#

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.

TABLE 3. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	(a) 1983	(a) 1984	(a) 1985	(b) 1986	(c) 1987	(c) 1988	(d) 1989	(d) 1990
4T4-4	-	0.72	0.42	0.185	0.56	0.079	#	#
4T4-5	-	-	0.58	0.58	4.3	1.12	#	#
4T4-6	-	-	0.22	0.16	0.61	0.188	#	#
4T4-7	-	-	0.44	0.29	0.64	0.22	#	#
4T4-8	-	-	0.42	0.193	0.40	0.23	#	#
4T4-9	-	-	0.50	0.21	0.27	0.073	#	#
4T4-10	-	-	0.42	0.22	0.29	0.063	#	#
4T4-11	-	-	0.40	0.60	2.7	1.27	#	#
4T4-12	-	-	-	0.75	3.4	1.35	#	#
4T4-13	-	-	-	-	-	-	#	#
4T4-14	-	-	-	-	-	-	#	#
4T4-15	-	-	-	-	-	-	#	#
4T4-16	-	-	-	-	-	-	#	#
4T4-17	-	-	-	-	-	-	#	#
4T4-18	-	-	-	-	-	-	#	#
4T4-19	-	-	-	-	-	-	#	#
4T4-20	-	-	-	-	-	-	#	#
4S1-1	-	-	-	-	8.5	12.2	11.6	15.7
4S2-1	-	-	-	-	0.155	0.109	0.032	0.068
4S3-1	-	-	-	-	0.65	1.73	0.73	0.87

a = antennas not constructed.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.

TABLE 4. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

Site No., Meas. Pt.	1983 (a)	1984 (a)	1985 (a)	1986 (b)	1987 (c)	1988 (c)	1989 (d)	1990 (d)
4C1-6	-	0.003	0.003	0.003	0.002	0.003	0.002	0.002
4C1-7	-	0.003	0.002	0.001	0.003	0.002	0.001	0.002
4C1-8	-	0.003	0.003	0.002	0.003	0.002	0.001	0.002
4C1-9	-	0.003	0.003	0.002	0.001	0.002	0.002	0.002
4C1-10	-	-	0.002	0.002	0.002	0.002	0.002	0.002
4C1-11	-	-	0.002	0.002	0.002	0.002	0.001	0.002
4C1-12	-	-	0.002	0.003	0.001	0.002	0.001	0.002
4C1-13	-	-	0.002	0.003	0.001	0.003	0.002	0.002
4T2-3	-	0.002	0.001	0.001	0.003	0.005	#	#
4T2-4	-	-	0.001	0.001	0.003	0.006	#	#
4T2-5	-	-	0.001	0.007	0.017	0.030	#	#
4T2-6	-	-	0.001	0.006	0.006	0.014	#	#
4T2-7	-	-	0.001	0.004	0.004	0.007	#	#
4T2-8	-	-	0.001	0.002	0.004	/	#	#
4T2-9	-	-	0.001	0.003	0.003	0.005	#	#
4T2-10	-	-	0.001	0.003	0.003	0.005	#	#
4T2-11	-	-	0.001	0.004	0.005	0.007	#	#
4T2-12	-	-	0.002	0.004	0.005	/	#	#
4T2-13	-	-	0.001	0.005	0.008	0.013	#	#
4T2-14	-	-	0.002	0.011	0.018	0.029	#	#
4T2-15	-	-	-	-	-	-	#	#
4T2-16	-	-	-	-	-	-	#	#
4T2-17	-	-	-	-	-	-	#	#
4T2-18	-	-	-	-	-	-	#	#
4T2-19	-	-	-	-	-	-	#	#
4T2-26	-	-	-	-	-	-	-	#
4T2-33	-	-	-	-	-	-	-	#
4T2-34	-	-	-	-	-	-	-	#
4T2-35	-	-	-	-	-	-	-	#
4T2-36	-	-	-	-	-	-	-	#

a = antennas not constructed.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.

TABLE 4. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

Site No., Meas. Pt.	1983 (a)	1984 (a)	1985 (a)	1986 (b)	1987 (c)	1988 (c)	1989 (d)	1990 (d)
4T4-4	-	0.004	0.002	0.001	0.003	0.003	#	#
4T4-5	-	-	0.002	0.006	0.010	0.017	#	#
4T4-6	-	-	0.002	0.001	0.004	0.007	#	#
4T4-7	-	-	0.001	0.001	0.004	0.005	#	#
4T4-8	-	-	0.002	0.001	0.004	0.005	#	#
4T4-9	-	-	0.002	0.001	0.002	0.003	#	#
4T4-10	-	-	0.001	0.001	0.002	0.002	#	#
4T4-11	-	-	0.002	0.002	0.012	0.019	#	#
4T4-12	-	-	-	0.002	0.010	0.016	#	#
4T4-13	-	-	-	-	-	-	#	#
4T4-14	-	-	-	-	-	-	#	#
4T4-15	-	-	-	-	-	-	#	#
4T4-16	-	-	-	-	-	-	#	#
4T4-17	-	-	-	-	-	-	#	#
4T4-18	-	-	-	-	-	-	#	#
4T4-19	-	-	-	-	-	-	#	#
4T4-20	-	-	-	-	-	-	#	#
4S1-1	-	-	-	-	0.035	0.043	0.052	0.052
4S2-1	-	-	-	-	0.003	0.002	0.002	0.001
4S3-1	-	-	-	-	0.036	0.095	0.028	0.030

a = antennas not constructed.
b = antennas grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 A current.

- = measurement point not established.
/ = measurement not taken.
= measurement precluded by antenna operation.

TABLE 5. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amps	1986 NEW 6 amps	1986 SEW 6 amps	1986 SEW 10 amps (EX)	1987 NS 15 amps	1987 EW 15 amps	1988 NS 75 amps	1988 EW 75 amps	1989 B 150 amps	1990 B 150 amps
4C1-6	<	<	<	*	<	<	<	<	<	<
4C1-7	<	<	<	*	<	<	<	<	<	<
4C1-8	<	<	<	*	<	<	<	<	<	<
4C1-9	<	<	<	*	<	<	<	<	<	<
4C1-10	<	<	<	*	<	<	<	<	<	<
4C1-11	<	<	<	*	<	<	<	<	<	<
4C1-12	<	<	<	*	<	<	<	<	<	<
4C1-13	<	<	<	*	<	<	<	<	<	<
4T2-3	<	<	0.004	0.007	0.002	0.014	0.006	0.125	0.142	0.110
4T2-4	<	<	0.005	0.008	0.001	0.014	0.017	0.113	0.149	0.122
4T2-5	0.018	<	0.092	0.153	0.003	0.23	0.033	2.6	1.31	1.16
4T2-6	<	<	0.005	0.008	0.003	0.013	0.014	0.142	0.138	0.148
4T2-7	<	<	0.007	0.012	0.001	0.018	0.020	0.165	0.173	0.177
4T2-8	<	<	0.004	0.007	0.002	0.012	/	/	0.124	0.112
4T2-9	<	<	0.005	0.008	0.002	0.010	0.019	0.137	0.116	0.119
4T2-10	<	<	0.004	0.007	0.002	0.011	0.020	0.112	0.113	0.076
4T2-11	<	<	0.003	0.005	0.002	0.012	0.010	0.130	0.22	0.180
4T2-12	<	<	0.002	0.003	0.002	0.014	/	/	0.095	0.096
4T2-13	<	<	0.005	0.008	0.002	0.012	0.010	0.121	0.125	0.130
4T2-14	0.030	<	0.155	0.26	0.003	0.186	0.026	2.5	1.66	1.94
4T2-15	-	-	-	-	-	-	-	-	2.3	1.67
4T2-16	-	-	-	-	-	-	-	-	1.92	1.84
4T2-17	-	-	-	-	-	-	-	-	0.69	0.59
4T2-18	-	-	-	-	-	-	-	-	0.28	0.21
4T2-19	-	-	-	-	-	-	-	-	0.107	0.105
4T2-26	-	-	-	-	-	-	-	-	-	0.182
4T2-33	-	-	-	-	-	-	-	-	-	0.141
4T2-34	-	-	-	-	-	-	-	-	-	0.144
4T2-35	-	-	-	-	-	-	-	-	-	0.24
4T4-36	-	-	-	-	-	-	-	-	-	4.7

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
< = measurement est. <0.001 based on earth E-field.
* = data cannot be extrapolated.

TABLE 5. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amps	1986 NEW 6 amps	1986 SEW 6 amps	1986 SEW 10 amps (EX)	1987 NS 15 amps	1987 EW 15 amps	1988 NS 75 amps	1988 EW 75 amps	1989 B 150 amps	1990 B 150 amps
4T4-4	<	<	0.006	0.010	0.002	0.005	0.008	0.028	0.067	0.058
4T4-5	0.033	0.008	0.20	0.33	0.019	0.27	0.089	1.31	4.8	3.8
4T4-6	0.005	<	0.023	0.038	0.002	0.021	0.011	0.064	0.175	0.117
4T4-7	<	<	0.006	0.010	0.002	0.015	0.008	0.090	0.133	0.129
4T4-8	<	<	0.008	0.013	0.002	0.016	0.007	0.083	0.145	0.145
4T4-9	<	<	0.009	0.015	0.001	0.008	0.009	0.047	0.095	0.072
4T4-10	<	<	0.007	0.012	0.001	0.001	0.011	0.057	0.112	0.085
4T4-11	<	0.005	0.38	0.63	0.025	0.43	0.20	4.4	5.0	4.6
4T4-12	0.055	0.005	0.43	0.72	0.017	0.30	0.150	2.1	4.5	3.8
4T4-13	-	-	-	-	-	-	-	-	0.26	0.21
4T4-14	-	-	-	-	-	-	-	-	0.88	0.84
4T4-15	-	-	-	-	-	-	-	-	2.7	2.6
4T4-16	-	-	-	-	-	-	-	-	5.9	5.4
4T4-17	-	-	-	-	-	-	-	-	4.5	4.3
4T4-18	-	-	-	-	-	-	-	-	4.8	3.8
4T4-19	-	-	-	-	-	-	-	-	1.16	0.96
4T4-20	-	-	-	-	-	-	-	-	0.32	0.183
4S1-1	-	-	-	-	<	<	<	<	<	<
4S2-1	-	-	-	-	<	<	<	<	<	<
4S3-1	-	-	-	-	<	<	<	<	<	<

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
< = measurement est. <0.001 V/m based on earth E-field.
* = data cannot be extrapolated.

TABLE 6. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amps	1986 NEW 6 amps	1986 SEW 6 amps	1986 SEW 10 amps (EX)	1987 NS 15 amps	1987 EW 15 amps	1988 NS 75 amps	1988 EW 75 amps	1989 B 150 amps	1990 B 150 amps
4C1-6	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.005	0.030	0.028
4C1-7	<0.001	<0.001	<0.001	*	0.005	0.006	0.024	0.023	0.091	0.085
4C1-8	<0.001	<0.001	<0.001	*	0.004	0.004	0.017	0.016	0.076	0.067
4C1-9	<0.001	<0.001	<0.001	*	0.002	0.002	0.007	0.006	0.030	0.022
4C1-10	<0.001	<0.001	<0.001	*	0.005	0.004	0.026	0.023	0.087	0.079
4C1-11	<0.001	<0.001	<0.001	*	0.006	0.005	0.028	0.028	0.113	0.103
4C1-12	<0.001	<0.001	<0.001	*	0.004	0.003	0.016	0.016	0.068	0.072
4C1-13	<0.001	<0.001	<0.001	*	0.002	0.002	0.012	0.011	0.051	0.044
4T2-3	1.31	0.22	6.3	10.5	1.36	15.2	7.7	76	131	140
4T2-4	1.05	0.22	5.0	8.3	1.70	10.7	6.2	68	135	129
4T2-5	1.18	0.24	5.3	8.8	1.46	12.7	8.2	62	86	105
4T2-6	1.11	0.27	4.4	7.3	2.2	12.4	10.4	56	105	101
4T2-7	1.13	0.23	5.3	8.8	1.31	9.7	8.8	71	90	89
4T2-8	1.32	0.25	5.7	9.5	1.81	15.8	/	/	141	135
4T2-9	1.17	0.21	5.1	8.5	1.46	13.7	7.1	63	119	125
4T2-10	0.97	0.22	4.1	6.8	1.84	10.5	8.1	50	96	91
4T2-11	1.14	0.21	5.0	8.3	2.2	10.7	9.6	122	182	170
4T2-12	1.06	0.21	4.3	7.2	1.93	13.5	/	/	99	114
4T2-13	1.12	0.64	5.4	9.0	1.74	14.9	8.2	71	138	144
4T2-14	1.07	0.175	5.1	8.5	1.66	14.3	6.6	56	124	121
4T2-15	-	-	-	-	-	-	-	-	73	82
4T2-16	-	-	-	-	-	-	-	-	88	86
4T2-17	-	-	-	-	-	-	-	-	104	105
4T2-18	-	-	-	-	-	-	-	-	95	99
4T2-19	-	-	-	-	-	-	-	-	107	107
4T2-26	-	-	-	-	-	-	-	-	-	210
4T2-33	-	-	-	-	-	-	-	-	-	113
4T2-34	-	-	-	-	-	-	-	-	-	152
4T2-35	-	-	-	-	-	-	-	-	-	136
4T2-36	-	-	-	-	-	-	-	-	-	155

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
* = data cannot be extrapolated.

TABLE 6. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amps	1986 NEW 6 amps	1986 SEW 6 amps	1986 SEW 10 amps (EX)	1987 NS 15 amps	1987 EW 15 amps	1988 NS 75 amps	1988 EW 75 amps	1989 B 150 amps	1990 B 150 amps
4T4-4	0.33	0.181	1.46	2.4	1.63	3.7	7.2	16.5	42	31
4T4-5	13.8	2.0	81.	135.	14.0	194.	68	910	2100	1670
4T4-6	1.22	0.22	6.2	10.3	2.2	12.9	10.3	62	140	117
4T4-7	0.94	0.175	5.5	9.2	2.0	14.1	9.1	62	119	135
4T4-8	0.91	0.188	5.3	8.8	1.36	10.7	6.8	65	106	113
4T4-9	0.29	0.130	1.32	2.2	1.08	3.0	7.5	18.1	47	42
4T4-10	0.29	0.169	1.63	2.7	1.35	3.9	5.1	16.0	39	43
4T4-11	0.59	1.82	89.	148.	10.7	178.	50	850	1870	1890
4T4-12	21.	2.2	118.	197.	13.8	260.	40	760	1950	1600
4T4-13	-	-	-	-	-	-	-	-	64	56
4T4-14	-	-	-	-	-	-	-	-	220	200
4T4-15	-	-	-	-	-	-	-	-	760	760
4T4-16	-	-	-	-	-	-	-	-	3000	3800
4T4-17	-	-	-	-	-	-	-	-	130	30
4T4-18	-	-	-	-	-	-	-	-	3200	3600
4T4-19	-	-	-	-	-	-	-	-	750	880
4T4-20	-	-	-	-	-	-	-	-	200	163
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/
4S2-1	-	-	-	-	0.005	0.005	0.026	0.026	0.126	0.103
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
* = data cannot be extrapolated.

TABLE 7. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 1 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amps	1986 NEW 6 amps	1986 SEW 6 amps	1986 SEW 10 amps (EX)	1987 NS 15 amps	1987 EW 15 amps	1988 NS 75 amps	1988 EW 75 amps	1989 B 150 amps	1990 B 150 amps
4C1-6	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003	0.003
4C1-7	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002	0.002
4C1-8	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002	0.002
4C1-9	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003	0.003
4C1-10	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002	0.002
4C1-11	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002	0.002
4C1-12	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	<0.001	0.002	0.002
4C1-13	<0.001	<0.001	<0.001	*	<0.001	<0.001	0.001	0.001	0.003	0.003
4T2-3	0.047	0.001	0.22	0.37	0.008	0.55	0.040	2.8	5.7	5.9
4T2-4	0.049	0.001	0.24	0.40	0.008	0.57	0.041	2.9	5.8	5.9
4T2-5	0.197	<0.001	1.00	1.67	0.011	2.4	0.061	12.4	24	27
4T2-6	0.058	0.001	0.44	0.73	0.006	1.16	0.020	5.0	10.3	11
4T2-7	0.046	0.001	0.22	0.37	0.006	0.59	0.024	2.6	5.4	5.8
4T2-8	0.045	0.001	0.22	0.37	0.006	0.59	/	/	5.6	5.8
4T2-9	0.029	0.001	0.138	0.23	0.007	0.38	0.027	1.72	3.4	3.6
4T2-10	0.033	0.001	0.149	0.25	0.006	0.39	0.027	1.78	3.5	3.7
4T2-11	0.043	0.001	0.21	0.35	0.006	0.56	0.025	2.6	5.0	5.3
4T2-12	0.047	0.001	0.23	0.38	0.006	0.61	/	/	5.6	5.9
4T2-13	0.086	<0.001	0.43	0.72	0.005	1.14	0.020	5.1	10.1	10.8
4T2-14	0.21	<0.001	1.03	1.72	0.012	2.5	0.061	11.9	25	28
4T2-15	-	-	-	-	-	-	-	-	33	36
4T2-16	-	-	-	-	-	-	-	-	28	29
4T2-17	-	-	-	-	-	-	-	-	13.6	13.9
4T2-18	-	-	-	-	-	-	-	-	8.6	8.6
4T2-19	-	-	-	-	-	-	-	-	5.9	6.0
4T2-26	-	-	-	-	-	-	-	-	-	10.5
4T2-33	-	-	-	-	-	-	-	-	-	4.2
4T2-34	-	-	-	-	-	-	-	-	-	7.4
4T2-35	-	-	-	-	-	-	-	-	-	21
4T2-36	-	-	-	-	-	-	-	-	-	36

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
* = data cannot be extrapolated.

TABLE 7. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
(page 2 of 2)

SITE NO., MEAS.PT.	1986 NS 4 amps	1986 NEW 6 amps	1986 SEW 6 amps	1986 SEW 10 amps (EX)	1987 NS 15 amps	1987 EW 15 amps	1988 NS 75 amps	1988 EW 75 amps	1989 B 150 amps	1990 B 150 amps
4T4-4	0.019	<0.001	0.096	0.160	0.005	0.24	0.027	1.15	2.5	2.3
4T4-5	0.114	0.001	0.57	0.95	0.008	1.40	0.033	6.9	13.9	13.3
4T4-6	0.045	0.001	0.22	0.37	0.008	0.53	0.034	2.7	5.3	5.1
4T4-7	0.038	0.001	0.186	0.31	0.008	0.45	0.033	2.3	4.4	4.1
4T4-8	0.035	0.001	0.179	0.30	0.007	0.43	0.033	2.1	4.2	4.1
4T4-9	0.025	0.21	0.118	0.197	0.005	0.29	0.027	1.41	2.8	2.7
4T4-10	0.022	<0.001	0.116	0.193	0.005	0.27	0.027	1.33	2.7	2.6
4T4-11	0.161	0.001	0.80	1.33	0.011	1.89	0.042	8.9	18.7	19.1
4T4-12	0.115	0.001	0.58	0.97	0.010	1.37	0.041	7.1	14.5	13.4
4T4-13	-	-	-	-	-	-	-	-	2.7	3.8
4T4-14	-	-	-	-	-	-	-	-	7.0	7.0
4T4-15	-	-	-	-	-	-	-	-	11.9	12.0
4T4-16	-	-	-	-	-	-	-	-	18	14.6
4T4-17	-	-	-	-	-	-	-	-	14.3	13.6
4T4-18	-	-	-	-	-	-	-	-	16.8	15.7
4T4-19	-	-	-	-	-	-	-	-	9.8	9.1
4T4-20	-	-	-	-	-	-	-	-	5.9	5.4
4S1-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/
4S2-1	-	-	-	-	<0.001	<0.001	0.001	<0.001	0.002	0.001
4S3-1	-	-	-	-	<0.001	<0.001	<0.001	<0.001	/	/

NS = north-south antenna.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas, standard phasing.
EX = extrapolated data.

- = measurement point not established.
/ = measurement not taken.
* = data cannot be extrapolated.

TABLE 8. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Antenna Site Fixed Test Points
(page 1 of 2)

Test Point	28-Jun-90	10-Jul-90	24-Jul-90	07-Aug-90	21-Aug-90	04-Sep-90	18-Sep-90
4T2-3	140	135	139	145	142	141	139
4T2-4	129	128	124	125	126	127	126
4T2-5	105	99	97	94	102	99	104
4T2-6	101	100	96	97	100	94	96
4T2-7	89	86	84	82	80	84	81
4T2-8	135	130	142	143	132	138	133
4T2-9	125	122	119	116	120	118	117
4T2-10	91	87	88	88	87	89	88
4T2-11	170	168	160	158	168	165	168
4T2-12	114	114	113	114	110	110	106
4T2-13	144	142	144	145	144	146	146
4T2-14	121	115	117	113	118	117	122
4T2-16	91	88	85	81	90	91	90
4T2-19	107	106	106	103	106	105	106
4T2-20	107	107	102	108	107	105	106
4T2-21	143	139	122	132	139	142	139
4T2-22	98	92	91	85	93	86	89
4T2-23	114	108	109	107	112	109	115
4T2-24	120	121	114	112	117	117	120
4T2-25	115	60	117	121	116	114	115
4T2-26	210	204	203	213	206	199	198
4T2-27	118	112	124	130	119	116	115
4T2-28	151	151	153	157	152	153	152
4T2-29	55	55	61	63	53	53	54
4T2-30	106	105	113	122	110	107	112
4T2-31	94	96	98	99	99	100	101
4T2-32	75	73	73	72	74	74	75

TABLE 8. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Antenna Site Fixed Test Points
(page 2 of 2)

Test Point	02-Oct-90	22-Oct-90	07-Nov-90	05-Dec-90	21-Dec-90	04-Jan-91	18-Jan-91
4T2-3	141	143	147	153	157	147	144
4T2-4	126	126	125	120	121	112	117
4T2-5	105	111	108	110	106	108	111
4T2-6	97	106	104	104	105	112	119
4T2-7	85	87	87	88	83	95	101
4T2-8	137	141	143	141	145	149	150
4T2-9	119	122	122	136	141	137	134
4T2-10	92	97	95	96	98	100	99
4T2-11	168	177	171	123	125	139	131
4T2-12	108	114	116	154	163	161	162
4T2-13	143	147	146	156	160	180	169
4T2-14	124	127	126	122	125	113	121
4T2-16	96	97	99	94	95	81	85
4T2-19	106	107	107	105	106	98	103
4T2-20	107	111	110	114	121	129	122
4T2-21	140	149	144	141	144	141	128
4T2-22	93	90	89	85	85	86	89
4T2-23	115	126	122	113	115	106	107
4T2-24	123	127	126	128	123	121	130
4T2-25	114	118	120	129	129	138	135
4T2-26	197	210	219	226	224	249	239
4T2-27	116	129	133	124	131	149	146
4T2-28	153	149	151	152	149	178	168
4T2-29	53	53	59	53	54	70	70
4T2-30	113	115	124	120	122	130	129
4T2-31	100	102	102	103	104	103	104
4T2-32	74	75	73	72	75	58	63

TABLE 9. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Ground Site Fixed Test Points
(page 1 of 2)

Test Point	28-Jun-90	10-Jul-90	24-Jul-90	07-Aug-90	21-Aug-90	04-Sep-90	18-Sep-90
4T4-4	31	29	27	28	31	31	32
4T4-5	1670	1796	1830	1954	2100	2039	2021
4T4-6	117	115	115	125	136	138	141
4T4-7	135	132	130	132	137	135	137
4T4-8	113	108	105	106	109	105	108
4T4-9	42	42	42	43	42	43	43
4T4-10	32	30	30	30	30	29	32
4T4-11	1890	1941	2191	2304	2030	2084	2045
4T4-12	1600	1611	1698	1815	1850	1822	1899
4T4-21	109	107	91	97	122	127	131
4T4-22	148	137	139	148	153	154	159
4T4-23	333	337	329	351	380	368	385
4T4-24	360	360	344	344	393	381	409

TABLE 9. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Ground Site Fixed Test Points
(page 2 of 2)

Test Point	02-Oct-90	22-Oct-90	07-Nov-90	05-Dec-90	21-Dec-90	04-Jan-91	18-Jan-91
4T4-4	32	12.0	9.0	8.7	8.3	6.8	7.1
4T4-5	1975	1721	1742	1981	1912	2110	2102
4T4-6	143	148	140	142	140	131	131
4T4-7	139	144	146	145	149	136	147
4T4-8	109	112	113	109	111	108	112
4T4-9	44	18.0	20	20	22	25	25
4T4-10	33	35	37	37	37	37	36
4T4-11	2030	2186	2237	2409	2542	2640	2836
4T4-12	1958	1822	1772	1820	1861	2460	2303
4T4-21	134	146	135	132	136	128	123
4T4-22	169	177	174	170	165	154	148
4T4-23	396	413	382	374	385	390	378
4T4-24	428	432	420	420	416	454	438

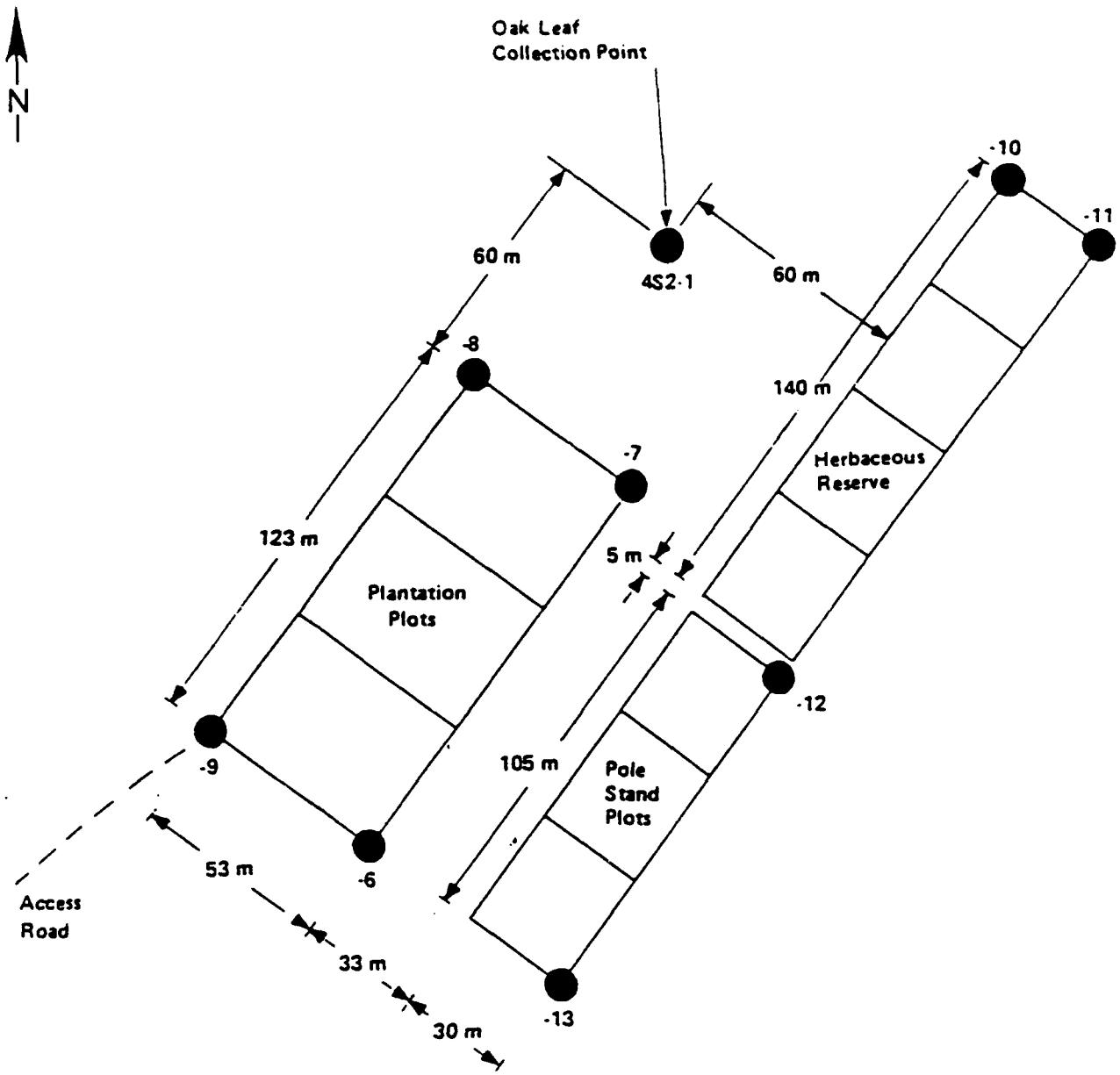

FIGURE 1. MEASUREMENT POINTS AT PAINT POND ROAD CONTROL; 4C1-6 THROUGH 13, AND OAK LEAF COLLECTION SITE; 4S2-1.

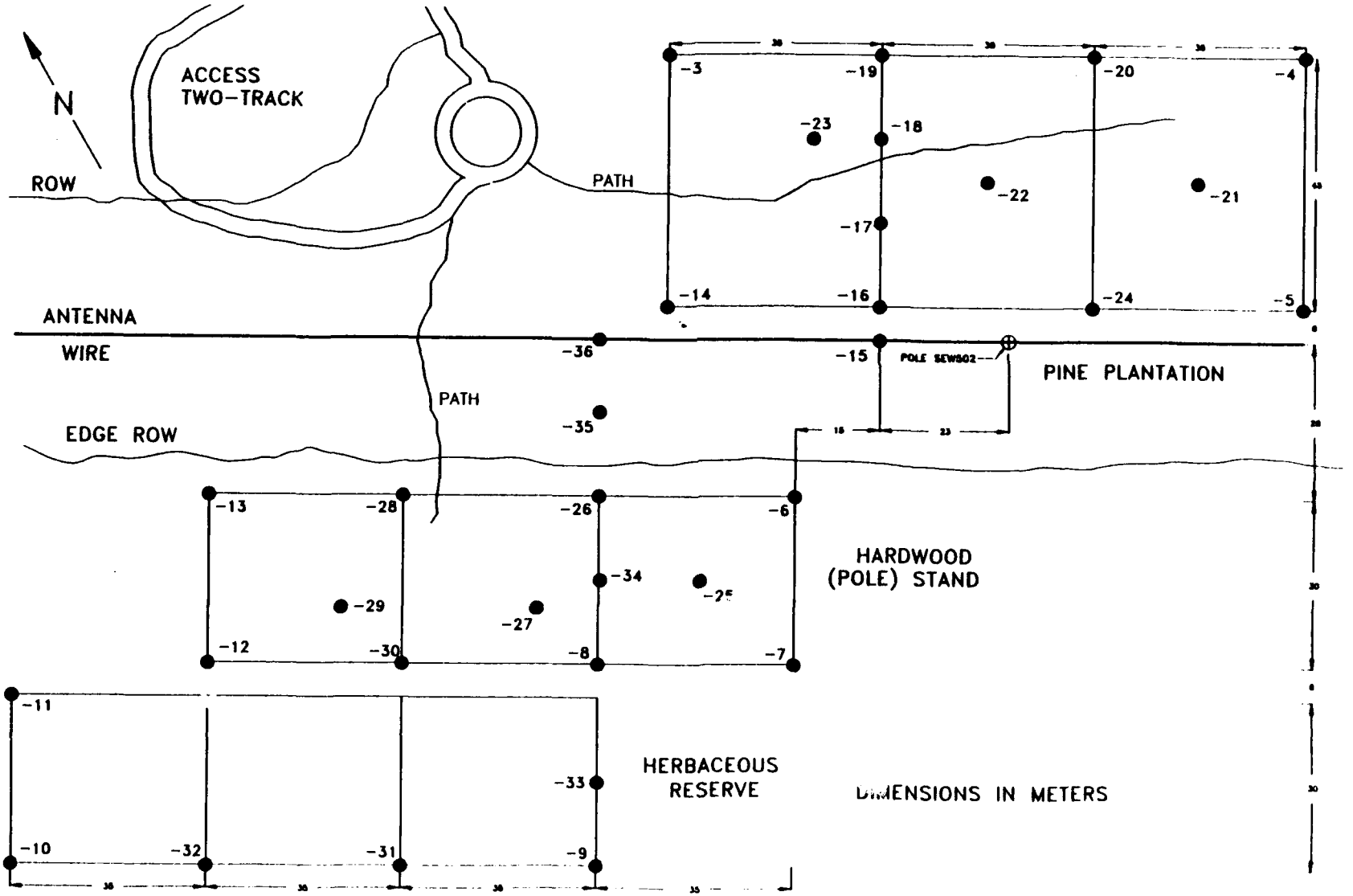

FIGURE 2. MTU ANTENNA SITE-MARTELL'S LAKE (OVERHEAD):ML
HISTORIC AND FIXED MEASUREMENT POINTS:4T2-3 THROUGH 36

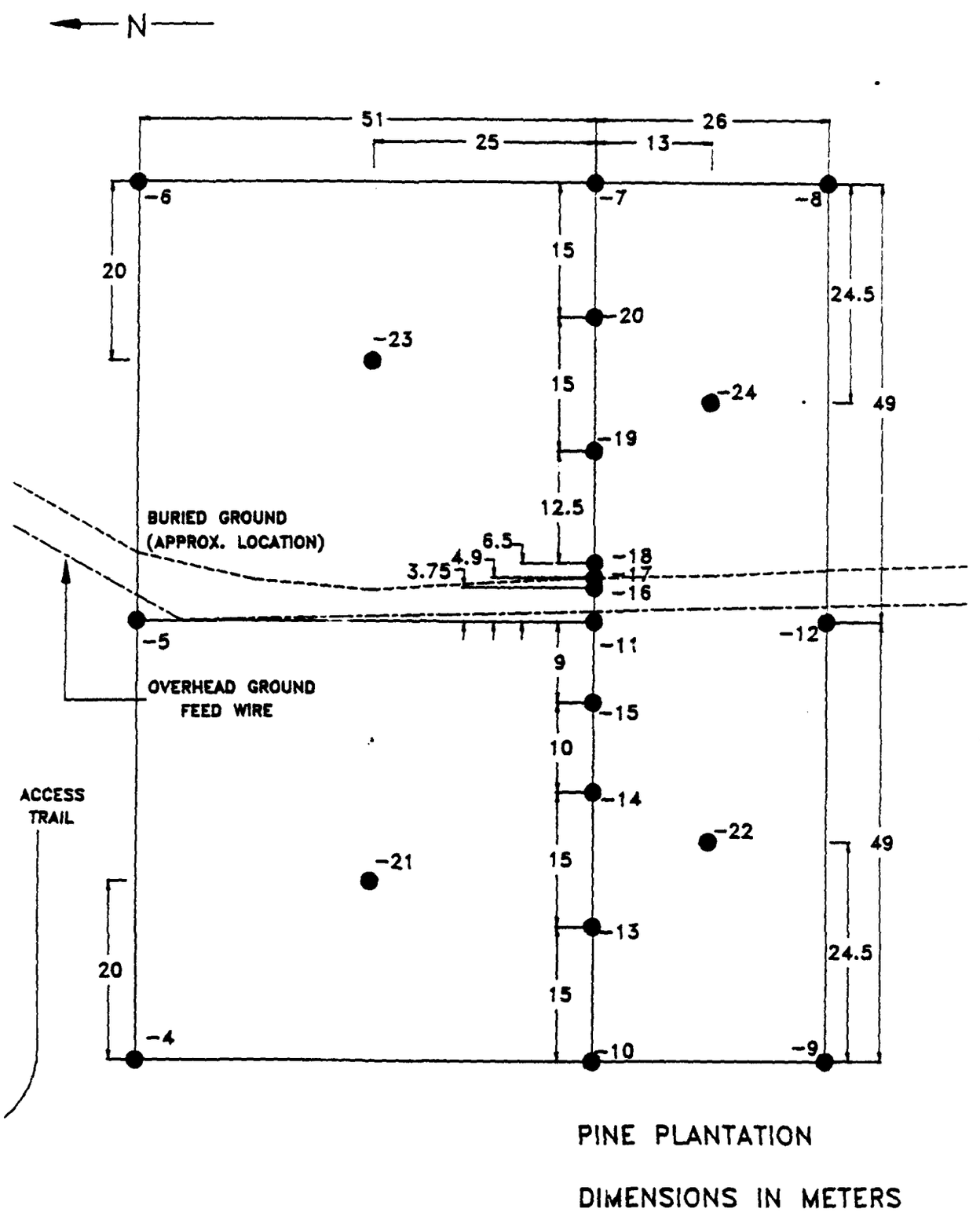

FIGURE 3. MTU GROUND SITE MARTELL'S LAKE (BURIED): EP HISTORIC AND FIXED PROBE POINTS; 4T4-4 THROUGH 24

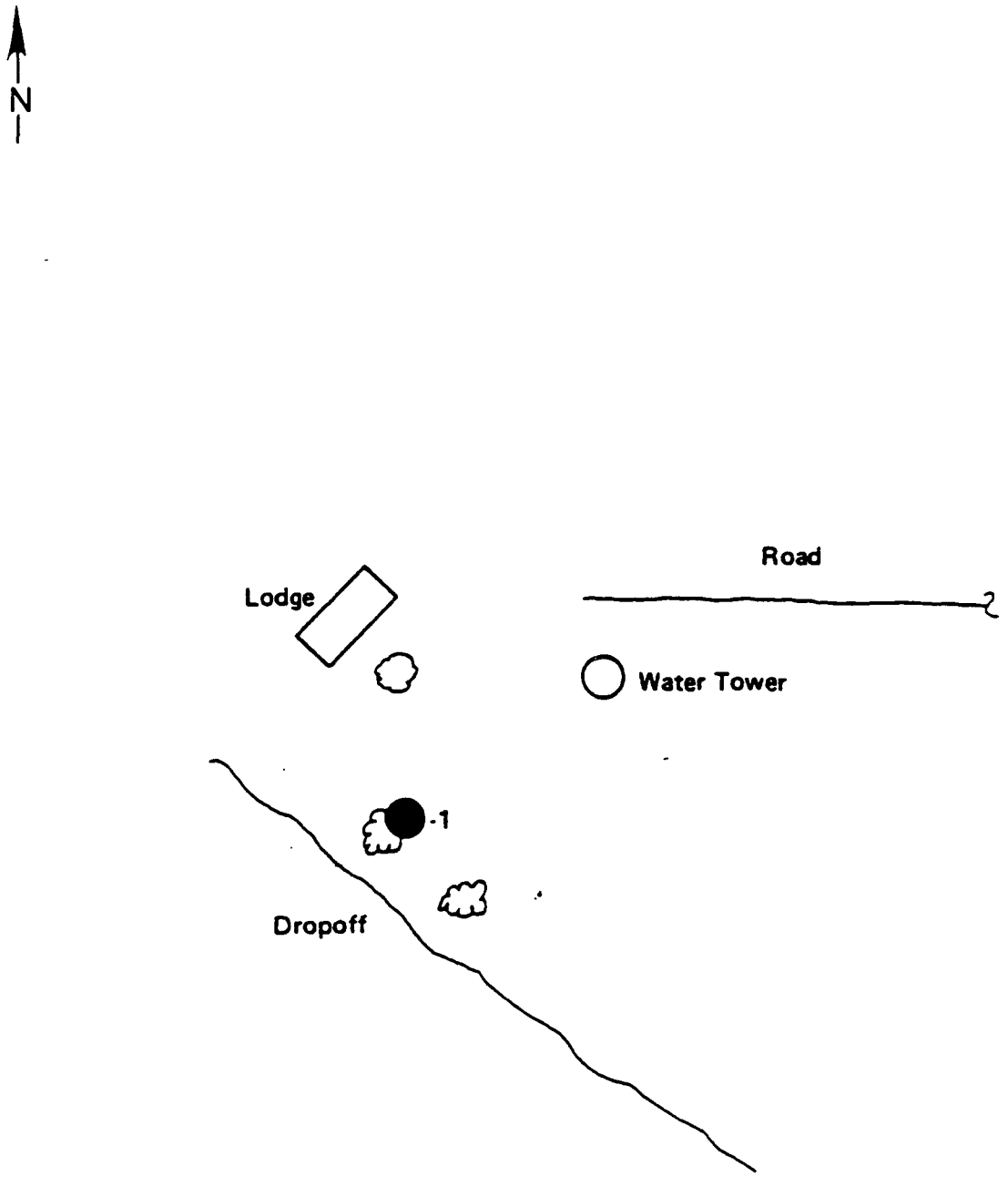

FIGURE 4. MEASUREMENT POINT AT RED MAPLE LEAF SAMPLE COLLECTION SITE; 4 S1-1.

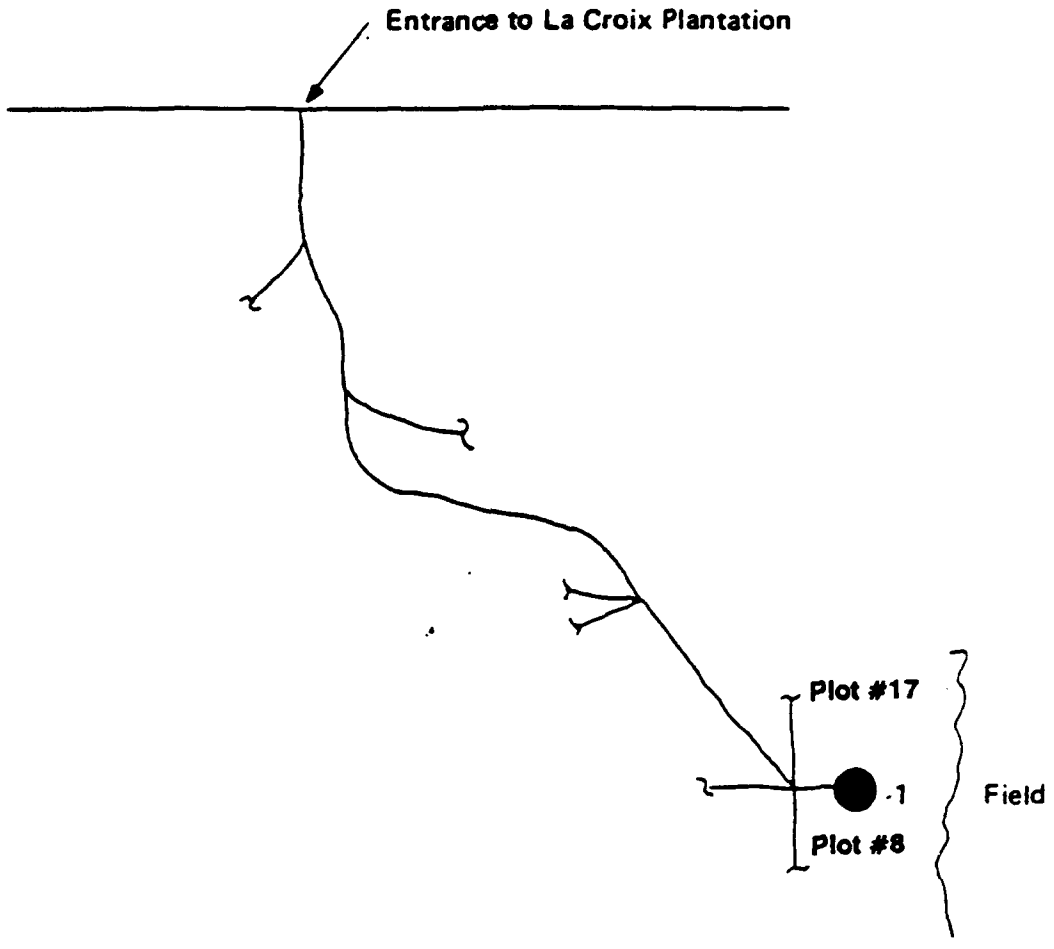

FIGURE 5. **MEASUREMENT POINT AT THE PINE NEEDLE SAMPLE COLLECTION SITE; 4S3-1.**

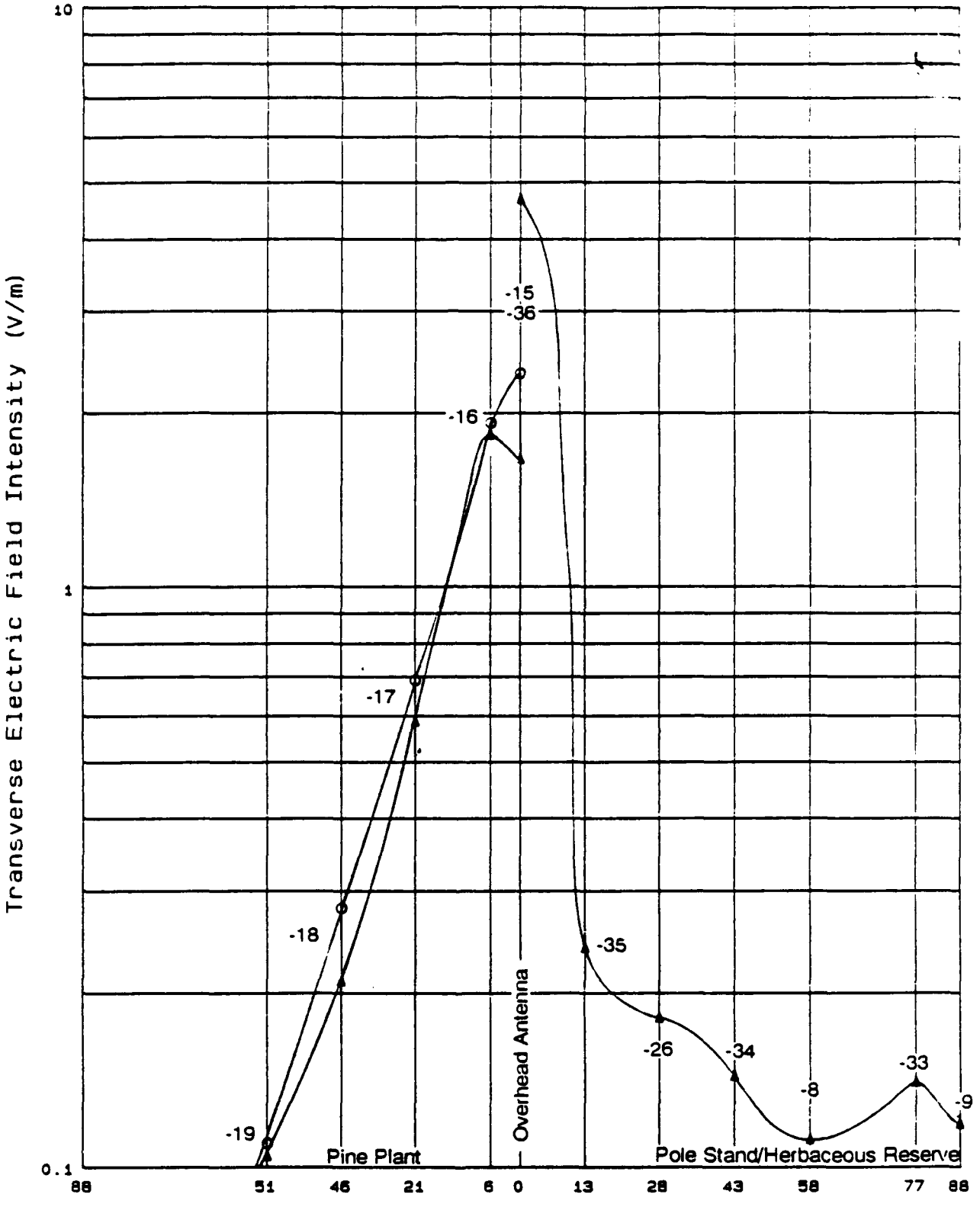

FIGURE 6. 76 Hz TRANSVERSE ELECTRIC FIELD PROFILES, MARTELL'S LAKE (OVERHEAD): ML; 4T2-8, 9, 15-19, 26, 33-36.

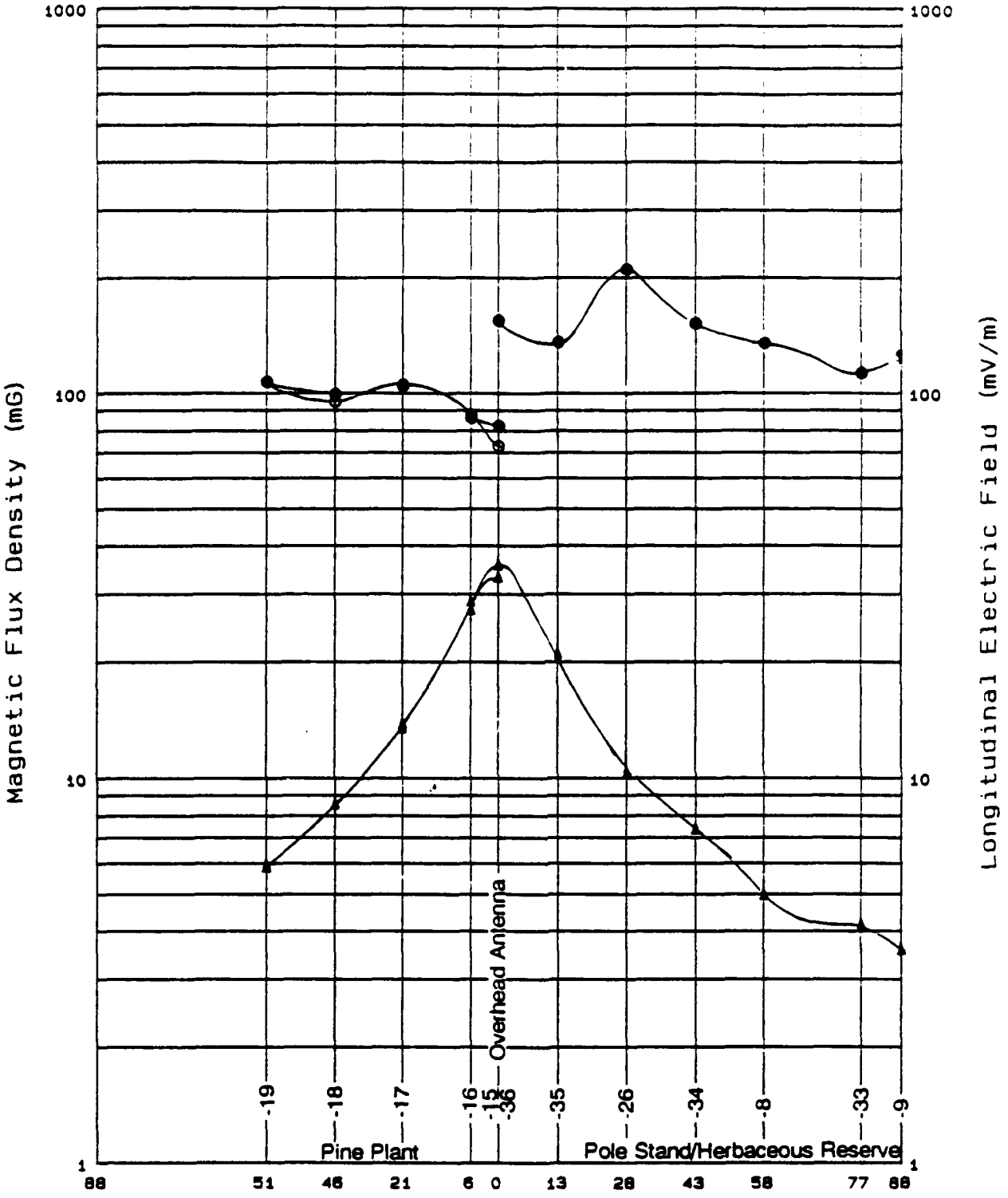

FIGURE 7. 76 Hz MAGNETIC & LONGITUDINAL ELECTRIC FIELD PROFILES, MARTELL'S LAKE (OVERHEAD): ML; 4T2-8, 9, 15-19, 26, 33-36.

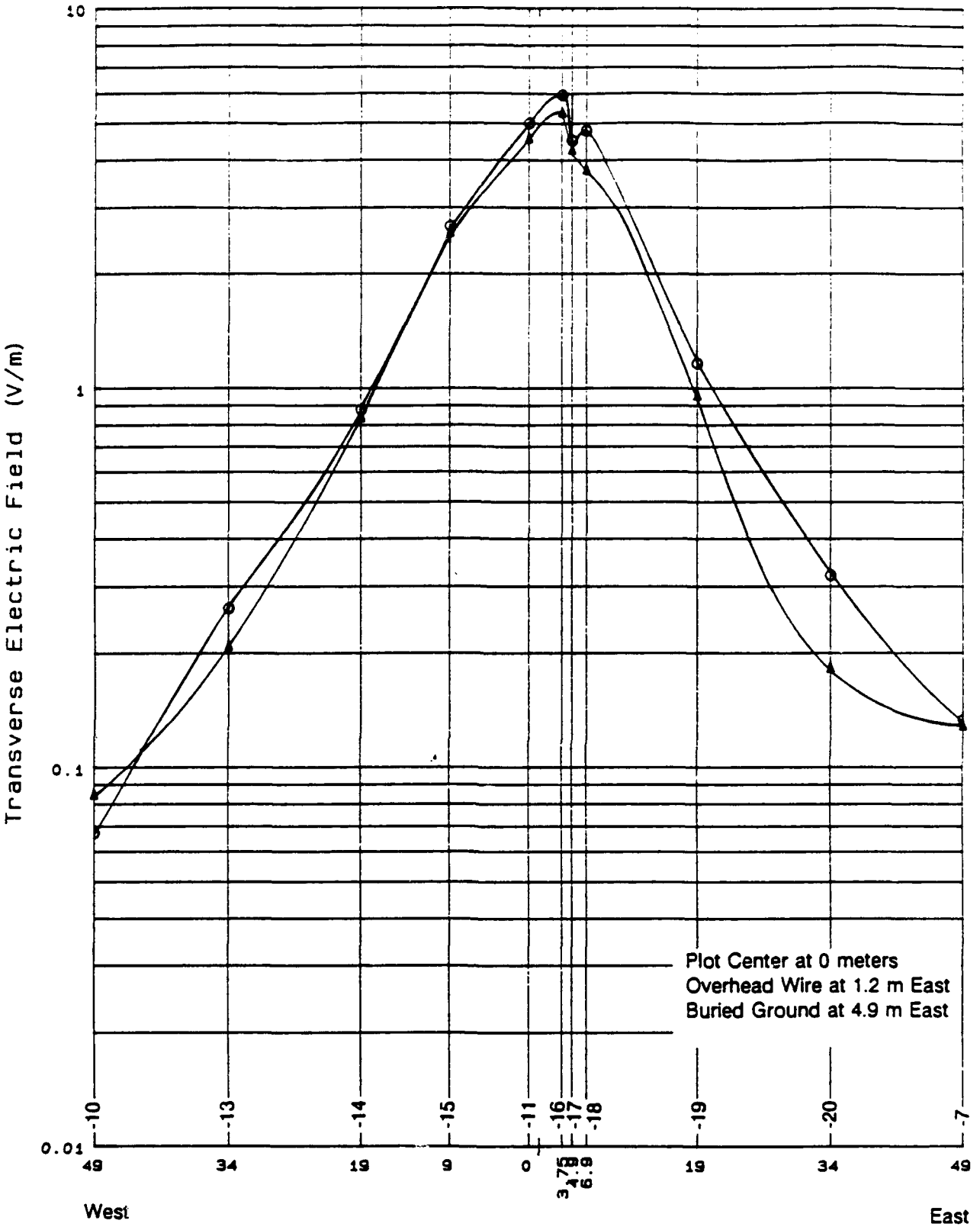

FIGURE 8. 76 Hz TRANSVERSE ELECTRIC FIELD PROFILE MARTELL'S LAKE (BURIED): EP; 4T4-7, 10, 11, 13-20.

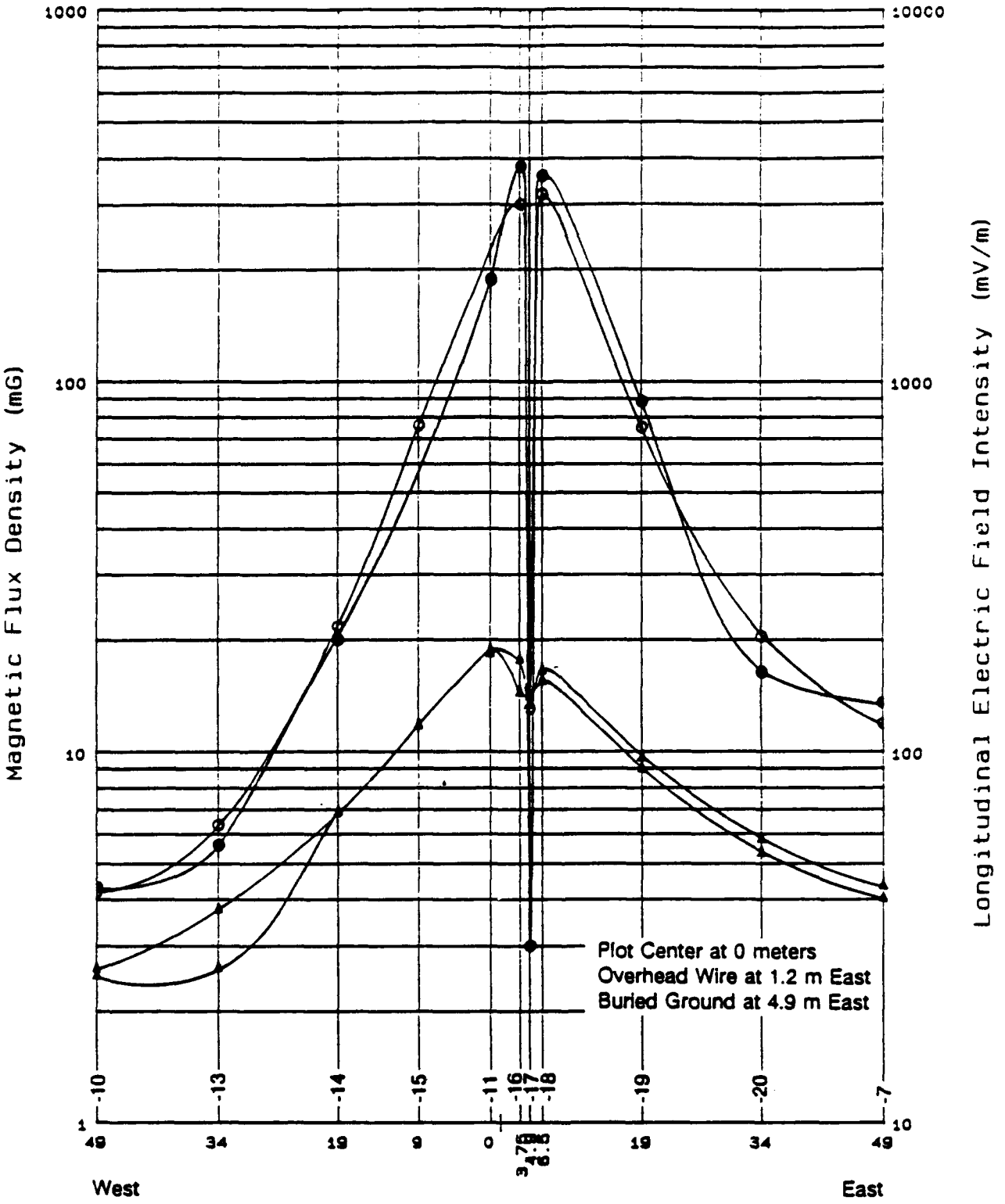

FIGURE 9. 76 Hz MAGNETIC & LONGITUDINAL ELECTRIC FIELD PROFILES MARTELL'S LAKE (BURIED): EP: 4T4-7, 10, 11, 13-20.

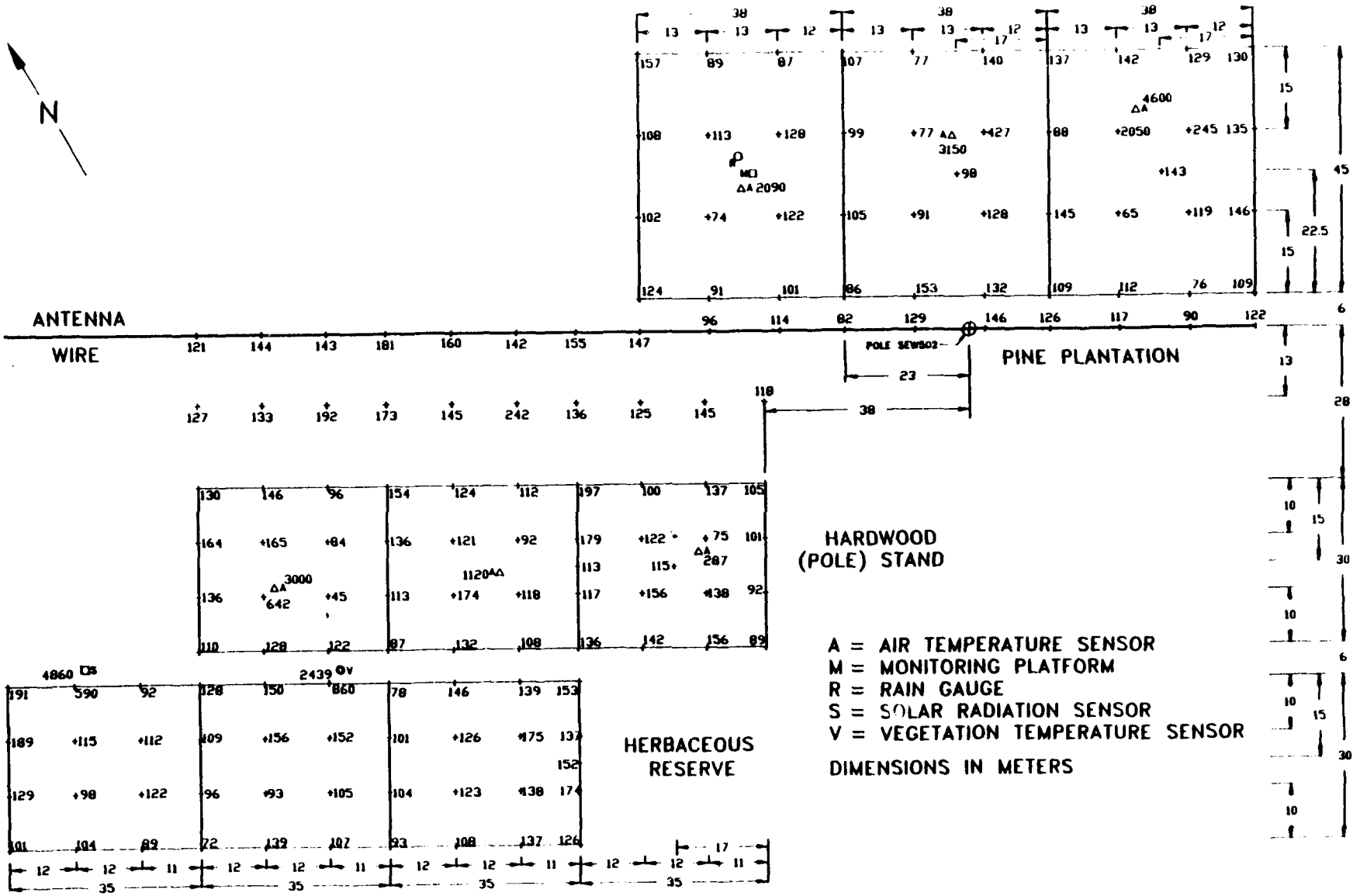

FIGURE 10. MTU ANTENNA SITE-MARTELL'S LAKE (OVERHEAD):ML
LONGITUDINAL E-FIELD SURVEY. 6/90 (mV/m)

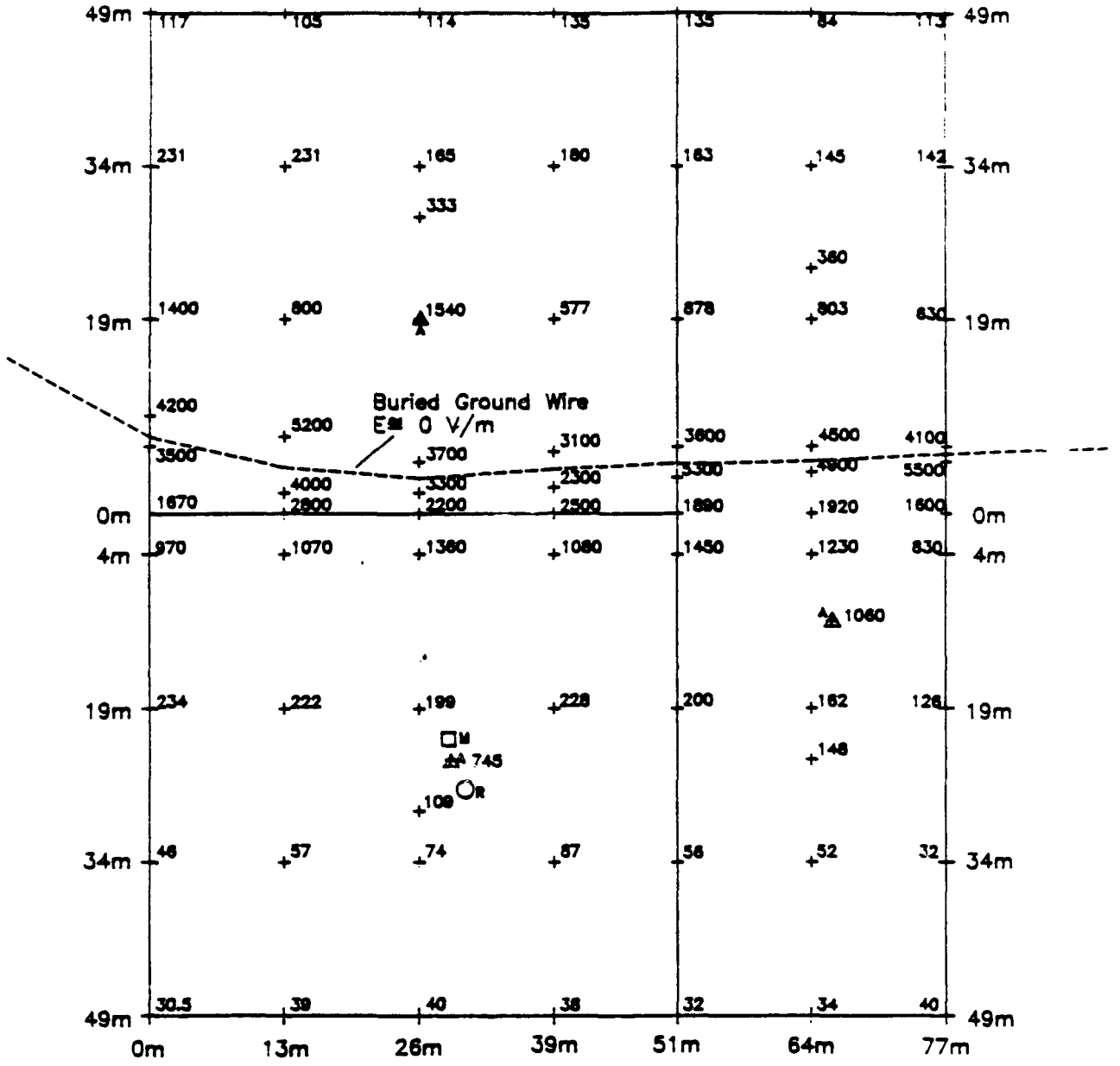

FIGURE 11. MTU GROUND SITE MARTELL'S LAKE (BURIED): EP LONGITUDINAL E-FIELD SURVEY, 6/90 (mV/m)

Table 1A. Estimated average yearly exposure levels by plot for control hardwood sites for 1985, 1986, 1987, 1988, 1989, 1990.

	1985	1986	1987	1988	1989	1990
60 H						
Transverse (V/m)						
Plot 1	0.0000	0.0000	0.0000	0.0000		
Plot 2	0.0000	0.0000	0.0000	0.0000		
Plot 3	0.0000	0.0000	0.0000	0.0000		
Longitudinal (mV/m)						
Plot 1	0.0490	0.0490	0.0490	0.0490		
Plot 2	0.0614	0.0614	0.0614	0.0614		
Plot 3	0.0738	0.0738	0.0738	0.0738		
Magnetic Flux (mG)						
Plot 1	0.0020	0.0020	0.0020	0.0020		
Plot 2	0.0020	0.0020	0.0020	0.0020		
Plot 3	0.0020	0.0020	0.0020	0.0020		
76 H						
Transverse EW (V/m)						
Plot 1	0.0000	0.0000	0.0000	0.0000	0.0010	
Plot 2	0.0000	0.0000	0.0000	0.0000	0.0010	
Plot 3	0.0000	0.0000	0.0000	0.0000	0.0010	
Longitudinal EW (mV/m)						
Plot 1	0.0000	0.0000	0.0000	0.0100	0.0400	0.0400
Plot 2	0.0000	0.0000	0.0000	0.0100	0.0500	0.0500
Plot 3	0.0000	0.0000	0.0000	0.0100	0.0700	0.0700
Magnetic Flux EW (mG)						
Plot 1	0.0000	0.0000	0.0000	0.0000	.0025	.0025
Plot 2	0.0000	0.0000	0.0000	0.0000	.0025	.0025
Plot 3	0.0000	0.0000	0.0000	0.0000	.0025	.0025

Table 1B. Estimated average yearly exposure levels by plot for control plantation sites for 1985, 1986, 1987, 1988, 1989, 1990.

	1985	1986	1987	1988	1989	1990
60 H						
Transverse (V/m)						
Plot 1	0.0000	0.0000	0.0000	0.0000		
Plot 2	0.0000	0.0000	0.0000	0.0000		
Plot 3	0.0000	0.0000	0.0000	0.0000		
Longitudinal (mV/m)						
Plot 1	0.0500	0.0500	0.0500	0.0500		
Plot 2	0.0646	0.0646	0.0646	0.0646		
Plot 3	0.0791	0.0791	0.0791	0.0791		
Magnetic Flux (mG)						
Plot 1	0.0020	0.0020	0.0020	0.0020		
Plot 2	0.0020	0.0020	0.0020	0.0020		
Plot 3	0.0020	0.0020	0.0020	0.0020		
76 H						
Transverse EW (V/m)						
Plot 1	0.0000	0.0000	0.0000	0.0000	0.0010	
Plot 2	0.0000	0.0000	0.0000	0.0000	0.0010	
Plot 3	0.0000	0.0000	0.0000	0.0000	0.0010	
Longitudinal EW (mV/m)						
Plot 1	0.0000	0.0000	0.0000	0.0100	0.0400	0.0400
Plot 2	0.0000	0.0000	0.0000	0.0100	0.0600	0.0600
Plot 3	0.0000	0.0000	0.0000	0.0200	0.0700	0.0700
Magnetic Flux EW (mG)						
Plot 1	0.0000	0.0000	0.0000	0.0000	0.0025	0.0025
Plot 2	0.0000	0.0000	0.0000	0.0000	0.0025	0.0025
Plot 3	0.0000	0.0000	0.0000	0.0000	0.0025	0.0025

Table 1C. Estimated average yearly exposure levels by plot for antenna hardwood site for 1985, 1986, 1987, 1988, 1989, 1990.

	1985	1986	1987	1988	1989	1990
60 H						
Transverse (V/m)						
Plot 1	0.0000	0.0000	0.0000	0.0038		
Plot 2	0.0000	0.0000	0.0000	0.0038		
Plot 3	0.0000	0.0000	0.0000	0.0038		
Longitudinal (mV/m)						
Plot 1	0.4939	0.3558	0.2849	0.2963		
Plot 2	0.4939	0.3558	0.2849	0.2963		
Plot 3	0.4939	0.3558	0.2849	0.2963		
Magnetic Flux (mG)						
Plot 1	0.0013	0.0040	0.0058	0.0097		
Plot 2	0.0011	0.0039	0.0056	0.0095		
Plot 3	0.0009	0.0037	0.0054	0.0093		
76 H						
Transverse EW (V/m)						
Plot 1	0.0000	0.0130	0.0356	0.0711	0.2238	
Plot 2	0.0000	0.0130	0.0356	0.0711	0.2238	
Plot 3	0.0000	0.0130	0.0356	0.0711	0.2238	
Longitudinal EW (mV/m)						
Plot 1	0.0000	10.5900	19.5400	88.1400	171.2300	187.3800
Plot 2	0.0000	8.9200	16.4500	74.2000	144.1700	157.7600
Plot 3	0.0000	7.4500	13.7400	61.9800	120.4200	131.7700
Magnetic Flux EW (mG)						
Plot 1	0.0000	0.3076	0.8092	3.4658	3.8945	3.8945
Plot 2	0.0000	0.3076	0.8092	3.4658	3.8945	3.8945
Plot 3	0.0000	0.3076	0.8092	3.4658	3.8945	3.8945

Table 1D. Estimated average yearly exposure levels by plot for antenna plantation site for 1985, 1986, 1987, 1988, 1989, 1990.

	1985	1986	1987	1988	1989	1990
60 H						
Transverse (V/m)						
Plot 1	0.0000	0.0000	0.0000	0.0051		
Plot 2	0.0000	0.0000	0.0000	0.0051		
Plot 3	0.0000	0.0000	0.0000	0.0051		
Longitudinal (mV/m)						
Plot 1	0.5126	0.3522	0.2869	0.2828		
Plot 2	0.5126	0.3522	0.2869	0.2828		
Plot 3	0.5126	0.3522	0.2869	0.2828		
Magnetic Flux (mG)						
Plot 1	0.0011	0.0048	0.0077	0.0130		
Plot 2	0.0009	0.0046	0.0075	0.0128		
Plot 3	0.0007	0.0044	0.0073	0.0126		
76 H						
Transverse EW (V/m)						
Plot 1	0.0000	0.0311	0.0614	0.4362	0.2983	
Plot 2	0.0000	0.0311	0.0614	0.4362	0.2983	
Plot 3	0.0000	0.0311	0.0614	0.4362	0.2883	
Longitudinal EW (mV/m)						
Plot 1	0.0000	8.7700	16.1900	73.0100	141.8500	155.2200
Plot 2	0.0000	8.7600	16.1500	72.8700	141.5700	154.9200
Plot 3	0.0000	9.2400	17.0400	76.8800	149.3700	163.4500
Magnetic Flux EW (mG)						
Plot 1	0.0000	0.4289	1.0977	4.9401	5.8803	5.8803
Plot 2	0.0000	0.4289	1.0977	4.9401	5.8803	5.8803
Plot 3	0.0000	0.4289	1.0977	4.9401	5.8803	5.8803

Table 1E. Estimated average yearly exposure levels by plot for ground plantation site for 1985, 1986, 1987, 1988, 1989, 1990.

	1985	1986	1987	1988	1989	1990
60 H						
Transverse (V/m)						
Plot 1	0.0000	0.0000	0.0004	0.0004		
Plot 2	0.0000	0.0000	0.0002	0.0002		
Plot 3	0.0000	0.0000	0.0003	0.0003		
Longitudinal (mV/m)						
Plot 1	0.3519	0.3519	1.7587	0.6104		
Plot 2	0.2851	0.2851	0.9544	0.4879		
Plot 3	0.3185	0.3185	1.1674	0.5491		
Magnetic Flux (mG)						
Plot 1	0.0016	0.0016	0.0058	0.0093		
Plot 2	0.0015	0.0015	0.0047	0.0067		
Plot 3	0.0015	0.0015	0.0052	0.0080		
76 H						
Transverse EW (V/m)						
Plot 1	0.0000	0.2506	0.2506	1.9393	2.0561	
Plot 2	0.0000	0.0727	0.0727	0.55312	0.8357	
Plot 3	0.0000	0.1616	0.1616	1.2462	1.4459	
Longitudinal EW (mV/m)						
Plot 1	0.0000	21.5300	34.5100	140.0000	395.8000	406.3600
Plot 2	0.0000	9.8400	15.7700	63.9700	180.8600	185.6800
Plot 3	0.0000	13.0400	20.9100	84.8200	239.7900	246.1900
Magnetic Flux EW (mG)						
Plot 1	0.0000	0.3430	0.8179	4.0315	27.1099	27.1099
Plot 2	0.0000	0.2231	0.5958	2.8562	29.5108	29.5108
Plot 3	0.0000	0.2831	0.7068	3.4439	28.3103	28.3103

To: Glenn Mroz

Date: October 16, 1991

From: Dave Reed

cc: M. Jurgensen
M. Gale
J. Bruhn
H. Liechty
R. Reed
P. Cattelino

Subject: 1990 ELF Field Exposure Information

The attached equations were developed for use in interpolating ELF magnetic flux exposure to any point within the study sites. The X coordinate in the equations is the distance from the antenna based on the IITRI maps (same as last year). Examples for selected point corners can be found in the memo from me to you in Appendix A of last year's report.

I combined the 1989 and 1990 exposure information to produce these equations. The antenna was operating at 150 amps both years and there were no apparent real differences in their measured values between 1989 and 1990. Hal and I have been working with Ann to develop a method for interpolating transverse and longitudinal information to point locations within the plots based on IITRI's maps provided last year. When completed, this will require us to provide a list of point coordinates for which we want field information. I'll keep you posted on progress here.

Equations

Control Site

Magnetic (76 Hz) mG = .0025

Antenna Site

Magnetic (76 Hz) mG = 15.82173 - .1717/X - .26437 * X

Ground Site

Magnetic (76 Hz) mG = 21.82629 + 1.33641/X - .2549 * X

Appendix B

Hardwood Growth Modeling Manuscript

MODELING DIAMETER GROWTH IN LOCAL POPULATIONS: A CASE STUDY INVOLVING FOUR NORTH AMERICAN DECIDUOUS SPECIES

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MODELING DIAMETER GROWTH IN LOCAL POPULATIONS: A CASE STUDY INVOLVING FOUR NORTH AMERICAN DECIDUOUS SPECIES

ABSTRACT

Many existing models representing the growth of forest overstory species as a function of environmental conditions make a number of assumptions which are inappropriate when applied to local populations. For example, maximum tree diameter and height are often assumed to be constant limiting factors for a given species even though growth functions can often be localized by utilizing information in the forest growth and yield literature to make site-specific estimates of these values. Most existing models also use an annual timestep which may be inappropriate when attepting to model the growth response of individual trees to environmental conditions. In this study, a model utilizing a weekly timestep is described and applied to four widespread North American deciduous tree species. Because response to environmental conditions can vary regionally due to genetic heterogeneity, the resulting model should not be considered as universally appropriate for these species. This study illustrates methods which can be utilized to develop models for application to local populations.

MODELING DIAMETER GROWTH IN LOCAL POPULATIONS: A CASE STUDY INVOLVING FOUR NORTH AMERICAN DECIDUOUS SPECIES

A number of recent studies have utilized information from forest growth models and exisiting forest monitoring data to investigate the effects of environmental stresses on forest productivity. Examples include the work by Holdaway (1987) investigating the regional effects of acidic deposition on forests in the northcentral United States and work by Botkin et al. (1989) projecting the possible effects of climate change on the forests of Michigan. These and similar studies utilize growth models to study the effects of an imposed environmental factor against a background of natural variability in climate and other factors.

There are a number of existing models which attempt to describe annual diameter growth as a function of tree and stand characteristics while accounting for the effect of site physical, chemical, and climatic properties. Diameter growth functions of the JABOWA (Botkin et al. 1972) and FORET (Shugart and West 1977) models and models of the type described by Reed (1980) and Shugart (1984) are examples. There have been a number of models developed recently but many of these utilize the growth functions based on the methods presented in these earlier papers. In any case, most models are based on certain species-specific characteristics (such as maximum observed diameter and height) and observations relating site physical, chemical,

and climatic conditions to species productivity (such as the climatic conditions at the limits of the species' geographic range).

Productivity here is defined as annual aboveground overstory biomass accumulation. While monitoring of actual biomass production over time is not feasible in field situations, it is relatively easy to accurately and precisely measure cambial development. There is a strong relationship between a tree's diameter at breast height and total tree biomass (Crow 1978). Furthermore, cambial activity is strongly related to climatic variation, competition from neighboring trees, and site physical and chemical properties (Smith 1986, Spurr and Barnes 1980). For these reasons, diameter increment was chosen as the response variable representing biomass increment.

The diameter growth functions of the JABOWA and FORET models were tested by Fuller et al. (1987) on the two study sites described below and found to perform poorly when compared to actual field measurements. For all species on the sites, the models proved to be poorer predictors of individual tree diameter increment than simply using the mean diameter growth of the stands. Desanker et al. (1991) extended these comparisons over a total of seven growing seasons and also included the growth functions from the STEMS (Belcher et al. 1982) and FOREST (Ek and Monserud 1974) growth models. Average differences of at least 200 percent between observed and predicted diameter increments

were observed for each of the models for at least one year with some differences as high as 3000 percent. Clearly, such errors are unacceptable when attempting to evaluate the effects of forest stress factors which may impact growth by less than 100 percent. Desanker et al. (1991) conclude that forest growth models can not simply be taken off the shelf and applied to any site (even within the geographic range of the models) without somehow adjusting for local site conditions.

There are several reasons for the inaccuracy of the predictions made by these models. An annual timestep may not be adequate when attempting to quantify the effects of environmental stress on forest productivity. Charles-Edwards et al. (1986) indicate that the amount of time for individual plant growth processes to stabilize following a pertubation in the nutrient status of the rooting environment to be on the order of 10^5 seconds (a few days) and the recovery time of a natural system to be on the order of 10^9 seconds (many years). It is illogical to use a timestep which is longer than the recovery time of the system of interest, whether that system is an individual plant or plant community. It is also counter-productive to use a timestep that is many orders of magnitude less than the recovery time of the system of interest. Since the interest here involves individual plants and their response to competition from neighboring plants as well as environmental factors, an intermediate timestep of one week

was utilized in developing a diameter growth model of the type described by Reed (1980).

Models of the type described above may also perform poorly on specific sites because the species attributes they utilize are not applicable across the entire geographic range of a species. The maximum expected diameter and height for a species is dependent on genotype and site conditions and is not constant over the entire range of the species. There is a great amount of information in the forest growth and yield literature relating tree growth and development to site quality class or site index which can be utilized to make forest growth models more site specific.

A diameter growth model using site specific species attributes and observed relationships between diameter growth, competition, and site physical, chemical, and climatic properties is presented below for two study sites in Upper Michigan. The purpose is to develop a model which can be used to estimate the effects of an imposed environmental factor against a background of natural environmental variability in a local population. The relationships given here reflect the genotypes and environmental conditions on the study sites and can not be expected to extend over the entire geographic ranges of these species. The methodology for identifying and quantifying these relationships is applicable to other study sites and species.

METHODS

Site Description

The two study sites are located in the central Upper Peninsula of Michigan. Site one is at 46°10'N, 88°30'W and site two is at 46°20'N, 88°10'W. Both sites have relatively undisturbed second growth deciduous vegetation consisting principally of red maple (Acer rubrum, L.) and northern red oak (Quercus rubra, L.) with minor components of quaking aspen (Populus tremuloides, Michx.), bigtooth aspen (Populus grandidentata, Michx.), and paper birch (Betula papyrifera, Marsh.). The sites are both characterized as the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983). The soil at site one is classified as an alfic haplorthod, sandy, mixed, frigid and the soil at site two is classified as an entic haplorthod, sandy, mixed, frigid (USDA Soil Conservation Service 1975). Past studies have documented similar northern deciduous forest productivity on these two soil types (Shetron 1972). Both sites are within the same regional ecosystem (Iron District, Crystal Falls Subdistrict (Albert et al. (1986)). The study sites are typical of forests on well-drained sandy soils of the region.

Field Measurements

Measurement of radial increment was accomplished using a band dendrometer as described by Cattelino et al. (1986). The dendrometer bands were read weekly to the nearest 0.008 cm of diameter. Dendrometer bands of this type have the ability to measure diurnal shrinking and swelling of the tree bole which introduces some variability into the measurements. By standardizing the day of the week and approximate time of day to make measurements, and by following individual trees over a number of years, the negative effects of this measurement variability are minimized while the positive effects of being able to detect growth pattern across the season are maximized. Readings began in early April and continued through the growing season until over 50 percent of leaf fall had taken place. There were 274 trees banded on site one and 197 trees banded on site two prior to the 1985 growing season. Weekly measurements were made over the 1985, 1986, 1987, and 1988 growing seasons. Locations of the individual trees were mapped on a Cartesian coordinate system with a 0.1 m resolution (Reed et al. 1989). Stand conditions at the beginning of the modeling efforts (1986) are given in Table 1.

The second category of field measurements include climate and soil properties which may affect plant growth processes. Each study site was equipped with a remote data

collection platform located in a cleared area adjacent to the site. The main data collection platform contained sensors measuring precipitation, air temperature, relative humidity, and solar radiation; each of three 30 X 35 m plots at each site contained sensors measuring air temperature, soil temperature, and soil moisture content at 5 and 10 cm depths. Sensors were queried every 30 minutes and computed into three-hour mean values by the platform microprocessor. Precipitation data are logged once every three hours. Data were retrieved eight times daily via NOAA satellite transmissions. These daily climatological and soil data were then summarized into weekly averages to coincide with the dendrometer band readings for analysis. Physical descriptions of each pedogenic soil horizon were made at the beginning of the study. The upper 15 cm of mineral soil were sampled monthly during the growing season for determination of nutrient levels.

GROWTH MODEL FORMULATION

The basic growth model formulation follows the conceptual model described by Botkin et al. (1972) and Reed (1980). In the model, the diameter growth during a given week, d_t, is represented as a function of tree, stand, climate, and site physical and chemical factors. These factors are incorporated in four model components:

1) Annual potential growth (PG);

2) The adjustment of annual potential growth due to intertree competition (IC);

3) The adjustment of annual potential growth due to site physical, chemical, and annual climatic properties (SPC);

4) The seasonal growth pattern and further adjustment of annual potential growth due to weekly climatic factors (SGP_t).

Each of the last three components is expressed as a proportion of the annual potential growth and the weekly diameter growth is expressed as the product of the four components:

d_t = (Annual Potential Growth) *
(Effect of Intertree Competition) *
(Effect of Site Physical, Chemical, and Climatic Properties) *
(Seasonal Growth Pattern and Effect of Weekly Climatic Conditions) [1]

Annual Potential Growth

In the above formulation, annual potential growth is defined as the amount of diameter growth that a tree could achieve if no environmental variables limit growth. Fuller

(1986) identified the model form given by Botkin et al. (1972) for use on these study sites. A slightly modified form of this model is used to represent potential growth (PG) on the study sites:

$$PG = \frac{G\ D\ (1 - D/D_{MAX})}{274 + 3\ b_2\ D - 4\ b_3\ D^2} \qquad [2]$$

where D is tree DBH (cm), D_{MAX} is the maximum observed tree diameter for a species (cm), and G, b_2, and b_3 are species specific constants. Botkin et al. (1972) included height and the species' maximum height (both in cm) in their model formulation; due to the difficulty in precisely measuring height and annual height growth in mature deciduous individuals, these variables were not directly included in the model formulation in this study. To insure logical predictions are obtained when D is near D_{MAX} (to insure that PG=0 when $D=D_{MAX}$ and $H=H_{MAX}$), Botkin et al. (1972) imposed the following constraints on b_2 and b_3:

$$b_2 = 2\ (H_{MAX} - 137)/D_{MAX} \qquad [3]$$

$$b_3 = (H_{MAX} - 137)/D_{MAX}^2 \qquad [4]$$

These constraints were imposed on b_2 and b_3 in this study as well to retain the logical behavior of PG.

Fuller (1986) and Desanker et al. (1991) found that the model with the values of the coefficients given by Botkin et al. (1972) performed poorly on the study sites and required re-estimation. As discussed by Botkin et al. (1972), Reed et al. (1990), and Desanker et al. (1991), this is at least partly due to the fact that H_{MAX} and D_{MAX} are site specific. Ek et al. (1984) gave an expression relating total tree height to DBH, site index, and stand basal area for each of the four species in this study. By using the observed site indices from the study plots and assuming an asymptotic stand basal area, the equations given by Ek et al. (1984) were utilized to estimate D_{MAX} and H_{MAX} for the study plots. An asymptotic basal area of 32 m^2/ha was chosen; basal areas exceeding this in mixed species stands of this type are possible on small plots, but very rare on the stand level. The final estimates of D_{MAX} and H_{MAX} are not sensitive to small changes in the selected asymptotic basal areas but can change dramatically when unrealistically high or low asymptotic basal areas are selected. Numerical procedures were used to solve the equations to find the diameter which would lead to insignificant (< 0.01 m) height growth; that diameter was taken as D_{MAX} for the site and the corresponding height was taken as H_{MAX}. The resulting estimates of D_{MAX} and H_{MAX} were used to fix b_2 and b_3 in the model as defined in the limiting relationships given above (Table 2).

Botkin et al. (1972) set G to produce approximately 2/3 of the maximum diameter at 1/2 of the maximum age. In this study, G was statistically estimated using nonlinear regression techniques (Table 2). For paper birch and aspen, asymptotic 99% confidence intervals around the estimated values of G included the values used by Botkin et al. (1972) and Shugart and West (1977) for these species. For red maple and northern red oak, this was not the case. The value of G incorporates various proportional relationships between total tree biomass increment, leaf area, and leaf biomass (Botkin et al. 1972). Therefore, it is not surprising that site specific values may be required for some species.

Intertree Competition

In the formulation of Botkin et al. (1972), and in following revisions by Shugart and West (1977) and others, the effect of intertree competition on diameter growth is represented in two ways. The first is through a model component representing light availability, which is based on tree height, the height of all other trees in the stand, and shade tolerance (two tolerance classes were used). The second is through a factor representing competition for moisture and nutrients which is simply a ratio of basal area

for the stand to maximum stand basal area expected for the cover type.

On these study sites, Holmes (1988) did not find a significant ($p > 0.05$) relationship between plot basal area and individual tree diameter growth. The comparison of the height of an individual tree to all other trees on a plot was also judged to be inappropriate, especially since these study plots measure 30 X 35 m and contain trees which are not measurably affecting each other.

Holmes and Reed (1992) used map information from the study plots to evaluate the performance of numerous individual tree competition indices for each of the four species. The competition indices used here are not necessarily those that were most highly correlated with individual tree diameter growth but they do perform well in the modeling efforts, especially in the combined model when other environmental factors are considered. A simple competition index given by Lorimer (1983) performed well for northern red oak, paper birch, and red maple. This index is given by:

$$CI_i = \sum \frac{DBH_j}{DBH_i} \qquad [5]$$

where CI_i is the value of the competition index for the ith (subject) tree, DBH_i is the diameter of the subject tree,

DBH_j is the diameter of the jth competitor, and the summation is over all trees within 7.62 m of the subject tree. Holmes and Reed (1992) found that the relationship between Lorimer's competition index and diameter growth did not differ between sites or across years (1985-1987) for northern red oak, paper birch, and red maple.

For aspen, the least shade tolerant of the four species in this study, the competition index given by Bella (1971) proved to be highly related to observed diameter growth. This index includes additional information regarding the distance to neighboring trees:

$$CI_i = \sum [(a_{ij}/A_i) * (DBH_j/DBH_i)^3] \qquad [6]$$

where CI_i is the value of the competition index for the ith (subject) tree, DBH_i is the diameter of the subject tree, DBH_j is the diameter of the jth competitor, A_i is the area of the influence zone (as defined by the open grown crown radius given by Ek (1974)) of the ith tree, and a_{ij} is the area of the overlap of the influence zones of the ith tree and the jth competitor. As with Lorimer's index and the other three species, the relationship between Bella's index and aspen diameter growth did not differ between sites or across years (1985-87).

A negative exponential relationship was assumed between diameter growth and increasing competition. In the diameter growth model, this is represented by:

$$IC = e^{-(a*CI)} \quad [7]$$

where IC is the intertree competition component of the diameter growth model, a is the coefficient to be estimated for each species, and CI is the value of the competition index for the respective tree. There were no significant differences between sites in the estimated value of a (Table 2).

Site Physical, Chemical, and Climatic Factors

For environmental factors such as moisture, temperature, and soil nutrient levels, there is expected to be a range of values where a species responds positively to increased amounts of the factor, a range of values where the factor is adequate for the species and there is little response to increases or decreases, and a range of values where the species responds negatively to increased amounts (Spurr and Barnes 1980, Reed et al. 1990). Reed et al. (1992) describe an intensive variable screening procedure that was used to identify a set of environmental variables for each species which were correlated, either positively or negatively, with diameter growth on the study sites. These variables were selected to be as independent of each other as possible; the environmental factors selected were used

in an analysis of covariance and accounted for significant differences in diameter growth between sites and among years.

A component was added to the diameter growth model to represent the effect of site physical, chemical, and climatic factors on growth. The environmental factors were accounted for in the model by a linear function constrained to produce the proportion of potential growth which might be expected:

$$SPC = \frac{(DBH + c_0 + c_1X_1 + c_2X_2 + c_3X_3)}{DBH} \quad [8]$$

where SPC is the effect of physical, chemical, and climatic factors on diameter growth and DBH is tree diameter. The particular environmental factors (X_k) and the associated constants (c_k) are species specific. The factors identified in this study were total seasonal air temperature growing degree days (April - September) on a 4.4° C basis for northern red oak, paper birch, and aspen and air temperature degree days through May for red maple, July soil potassium concentration (ppm) in the upper 15 cm of mineral soil for aspen and red maple, and soil water holding capacity (cm/cm) at a depth of 5 to 10 cm for red maple and at a depth of 10 to 30 cm for paper birch. The intercept (c_0) was not significant ($p > 0.05$) for northern red oak and paper birch

and was removed from the model for these two species (Table 2).

Seasonal Growth Pattern and Effect of Weekly Climatic Conditions

Fuller et al. (1987) found that cumulative total air temperature degree days (4.4° C basis) was the most significant environmental factor impacting the timing of diameter growth for all four species on both sites. Reed et al. (1990) modeled the proportion of annual growth expected in a given week using a difference form of a modified Chapman-Richards growth function and the cumulative air temperature degree days at the beginning and end of the week. This requires the implicit assumption that each species will respond to temperature up to a point and that further increases in degree days will not lead to increased growth.

Increased air temperature leads to increased plant respiration and evaporation which may result in decreased levels of soil moisture. The expected growth, given the cumulative air temperature degree days, will not be achieved if moisture is limiting. In the model, average soil water potential (-MPa) at a depth of 5 cm is used to indicate the level of moisture stress. At a value of water potential less than .101 -MPa, water is freely available to plants and

is not assumed to be limiting. At potentials greater than .101 -MPa, moisture may limit growth to some extent; plant response is assumed to be a simple exponential function of increasing soil water potential. If the observed average soil water potential for a week is less than .101 -MPa, a value of .101 -MPa was used in the estimation procedure.

The model component representing weekly growth combines the effects of cumulative air temperature degree days at the beginning (ATD_{t1}) and end (ATD_{t2}) of week t and average soil water potential at 5 cm in week t (SWP_t):

$$SGP_t = \left(e^{-(ATD_{t1}/d_1)^{d2}} - e^{-(ATD_{t2}/d_1)^{d2}}\right) * \left(e^{-d_3 (SWP_t - .101)}\right) \quad [9]$$

where SGP_t is the proportion of potential total annual growth expected in week t. The coefficients d_1, d_2, and d_3 are species specific coefficients and are estimated statistically using nonlinear regression techniques (Table 2).

Combined Model

The combined model, incorporating all four model components discussed above, was fitted to data from both

sites for the 1986 and 1987 growing seasons. This allowed the examination of site differences in the coefficients due to tree and climatic differences in the 1986 and 1987 growing seasons. There were no differences in any coefficient by site so the data were combined to estimate the coefficients for each species. Data from the 1988 growing season were used for testing, but were not used in estimating the coefficients. Predictions of total seasonal diameter growth were made for each tree and compared to the observed growth values. A studentized test on the average residual found no evidence of bias in the combined model for any species except for aspen (Table 3). In other words, the average residual was not different from zero ($p > 0.10$) for northern red oak, paper birch, and red maple. For aspen, the average residual was different from zero ($p = 0.01$), indicating a significant underprediction of observed growth by the combined model. This result is probably due to a number of factors, including the small sample size for aspen, the extreme genetic diversity found in aspen in the Lake States, and the clonal growth of aspen (Fowells 1965).

The standard error of the residuals in the estimation data is analogous to the square root of the mean squared error in ordinary linear regression. The standard error of the residuals in the estimation data set is less than the measurement increment (0.008 cm) for all species except aspen (Table 3). This implies that the model prediction is

within the measurement precision for those species and further improvement is unlikely.

The proportion of variation explained in total annual diameter growth (Table 3) is analogous to R^2 in linear regression and, for all four species, is in the range found by other studies in deciduous species (Harrison et al. 1986 for example). Further improvement in these values may not be possible at the study sites due to the precision of the field measurements and the rates of observed growth.

Residual Analysis

The analysis of the model's ability to predict growth is divided into two components: total annual growth and seasonal pattern of growth. The predicted total annual growth is obtained by summing the weekly growth predictions over the entire growing season. The predicted seasonal growth pattern is determined by the cumulative growth to any given week during the growing season.

Total Annual Growth

Annual residuals, by site, are given for each species in Table 4. These comparisons involve the sum of the predicted weekly diameter growth over a season compared to the total observed growth during the season. As mentioned

previously, the data from 1986 and 1987 were used in model estimation; the data from 1988 were not used in estimation. The 1988 comparisons between the observed and predicted values can, in some ways, be interpreted as a test of the model under new conditions. While the same trees measured in previous years are remeasured, the particular combination of weather conditions in 1988 are unique. Thus, while not being an independent test of the model, the 1988 comparisons can provide insight into model performance under conditions other than those in the estimation data set.

As seen in Table 4, for northern red oak and paper birch, the studentized 95% confidence limits for each of the three years on both sites include zero, indicating no significant deviation in growth from that predicted by the model. For red maple, the studentized 95% confidence intervals for both sites in 1986 and 1987 include zero, indicating unbiased model predictions during the years from which the estimation data were obtained. In 1988, there was a large negative residual at each site, and the residuals were not different between sites. This indicates that the model did not adequately represent the growing conditions in 1988 and that some factor or combination of factors led to a reduced average diameter growth rate for red maple which was not seen in previous years but which was apparent at both sites.

In searching for differences in environmental factors between 1988 and previous years, the major difference

appears to be related to moisture. Average air temperature at 2 m above the ground and average precipitation are not significantly different between years (Table 5), but relative humidity and soil water potential at 5 cm were significantly different in 1988 than previous years. This indicates the possibility of increased moisture stress in 1988. Red maple is a widespread tree species found on many types of sites; it is characteristic of bottomland, swampy, and moist sites but it often occurs under drier conditions (Harlow and Harrar 1969, Fowells 1965). Reduced moisture availability on the study sites in 1988, as indicated by soil water potential at 5 cm, could be the cause of the reduced growth compared to previous years. This emphasizes the necessity of data collection over a longer time period in order to fully evaluate the effect of climatic conditions on tree growth.

Aspen is the only species for which there is a mixed response between the two sites (Table 4). The residuals of total annual aspen diameter growth at site one have increased over the three year study period while they have remained relatively constant at site two. Both sites are located adjacent to a cleared area but the average distance from the edge to the individual aspen trees is roughly equal for the two sites. In addition, there is no difference in crown position between individuals at both sites; the aspen individuals in these mixed stands all tend to be dominant or codominant individuals. There was also no significant

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In searching for differences in environmental factors between 1988 and previous years, the major difference

difference in total leaf biomass produced at site one between 1988 and previous years. Taken together, these factors indicate that the aspen at site one could not be responding to an increased light environment in 1988. There is a greater red maple component at site one than site two and the aspen could be responding to reduced competition from red maple due to the reduction in red maple growth described above. If so, this is happening at site one and not site two and it is happening in the absence of increased light.

To summarize the total annual growth comparisons, the model performed well for two species (northern red oak and paper birch) at both sites for all three years. For one species (red maple), the model did not perform well in 1988 at either site. It is possible that this is due to decreased moisture availability as compared to previous years. These results emphasize the fact that each year represents a unique combination of environmental conditions and an extended sampling period is needed to fully understand the relationships between tree productivity and climate. For the fourth species (aspen), there is a divergence in model performance between the two sites. The cause of this is not obvious at this time but there does not appear to be a simple environmental or competitive explanation based on the available information from the sites.

Seasonal Growth Pattern

Seasonal growth pattern is driven in the model by cumulative air temperature degree days and soil water potential on a weekly basis. Differences between estimated and observed seasonal growth patterns are examined using the Kolmogorov-Smirnov procedure to compare the observed and predicted cumulative growth percentages for each week. If an environmental variable affecting seasonal growth pattern is not included in the model, the observed pattern should differ from the predicted pattern. An illustration of the observed and predicted growth pattern is given in Figure 1.

For northern red oak, there were no significant differences ($p > 0.05$) between the observed and predicted seasonal diameter growth patterns at either site in any of the three years. This indicates that there is no significant deviation from the seasonal diameter growth pattern predicted by the model.

For paper birch at site one, there were no significant differences between the observed and predicted seasonal growth pattern in any of the three years. At site two, there were significant differences ($p < 0.05$) between the observed and predicted seasonal growth patterns on one plot in all three years and in a second plot in 1987 and 1988; there were no differences on the third plot. It is not clear that these differences are due to any seasonal

difference in climatic conditions between the two sites. The overall effect was that the model predicted a lower proportion of growth early in the year compared to what was observed. As discussed earlier, the overall net effect did not include a difference in total annual growth. The differences may largely be due to small numbers of trees being included in the plot level comparisons.

There were no significant differences ($p > 0.05$) between the observed and predicted seasonal growth patterns for red maple at site one with the exception of one plot in 1986 and another plot in 1988. At site two, there was a significant difference ($p < 0.05$) on one plot in 1988 but not in 1986 or 1987 and no differences for the other two plots. There does not seem to be any pattern to these differences. For the majority of plots and years there was no difference between the observed and predicted seasonal growth patterns.

For aspen, there was a significant difference ($p < 0.05$) between the observed and predicted seasonal growth pattern for only one plot in one year (1988) at site one. This plot only contains a single aspen individual and, while this difference could be related to the increased aspen growth at site one, unless this difference is repeated in the future and found on other sites at site one there is no real evidence of a systematic inadequacy in the model's prediction of seasonal diameter growth pattern. At site two, there were no differences ($p < 0.05$) between observed

and predicted aspen seasonal growth pattern with the exception of one plot in 1986. In 1986, the studentized 95% confidence intervals for the total annual growth residuals did not include zero and this may be having an influence on the evaluation of seasonal growth pattern. This difference was not repeated in later years and, since it only occurred on one plot, does not seem to indicate a serious problem with the model.

In the seasonal growth pattern evaluations, comparisons were made on a plot basis (using the three plots at each site) rather than on the site level. There were a number of instances where individual plots differed in observed and predicted seasonal growth pattern for single years, but paper birch at site two was the only case where differences between the observed and predicted patterns were noted on all or most of the plots. Even here, there were no apparent climatic differences which seemed to have caused the model performance to deteriorate. Whatever the cause, it was not sufficient to be associated with an overall decrease of model performance in estimating total annual growth as discussed above.

CONCLUSIONS

Many existing models which represent tree growth as a response to climate contain assumptions which may be

adequate on a regional basis but which cause poor model performance on many individual sites. Species' maximum diameters and heights, for example, are utilized in many of these models and, while it is well known that these are site dependent, this fact is not recognized in most existing growth models. Another example is a species' response to climate. From provenance trials it is well known for many species that genetic material from different locations within a species' geographic range responds differently to climatic conditions at a given site (Carter 1991). In many existing models a species' growth response to a given heat sum is assumed to be constant, even though differences in heat sum are used to represent different sites. There are many problems, therefore, in utilizing existing models to project the response of local tree populations and ecosystems to changing environmental conditions.

For many species and localities, traditional forest growth and yield information can be utilized in localizing the dimensional limits in existing models. Due to the problems encountered when applying existing models to local populations, it is important to localize such models when applying them to historical data to investigate impacts of historical climatic or pollutant exposure conditions. In this study, methods were developed and illustrated which utilize height/diameter models from the literature to develop expressions for maximum tree height and diameter as a function of site index and maximum stand basal area. Such

methods of localizing existing growth models could be developed for many species in much of the world.

An annual time step may not be sufficient for modeling tree response to environmental conditions. Ecosystem level response to a shift in environmental conditions may be on the order of several years while an individual tree's response to changes in environmental conditions, such as moisture or nutritional status, is on the order of a few days. Also, the timing of events such as drought during the growing season is as critical as their intensity in determining their effect on tree growth. The amounts and timing of precipitation and the temperature pattern within a given year interact to make each year a unique combination of environmental factors affecting plant communities. for these reasons, a weekly timestep was utilized in modeling seasonal growth pattern and, by summation, total annual diameter growth on the study sites.

In this study, over two sites and three years, the model of seasonal and annual diameter growth performed well for two of the four species. For a third species, there was a growth reduction at both sites in the third year, most likely due to a combination of temperature and precipitation leading to a reduction in available water during the growing season. For the fourth species, there was an unexplained differential in model performance between the two sites. These results emphasize the need for site-specific information collected annually over an extended period in

order to fully understand and quantify the effects of environmental factors on forest productivity.

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Table 1. Stand Characteristics at the beginning of the study (1986).

Species	Average Diameter (cm)	Average Height (m)	Average Basal Area (m^2/ha)	Density (stems/ha)	Site Index (m @ 50)	Age (yrs.)
Site One						
Northern Red Oak	20.82	22.24	20.00	556	22	52
Paper Birch	16.30	20.63	2.92	127	18	54
Aspen	22.82	23.51	3.33	79	20	55
Red Maple	11.85	16.31	0.52	48	18	45
Site Two						
Northern Red Oak	22.69	17.62	6.57	143	21	47
Paper Birch	20.42	19.62	0.86	25	20	55
Aspen	25.37	20.27	2.43	48	21	50
Red Maple	15.23	16.43	7.78	410	17	42

Table 2. Coefficient estimates (and associated asymptotic 95% confidence limits for statistically estimated coefficients) for the four species.

Coefficient	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
Annual Potential Diameter Growth Component				
Site Index (M@50)				
Site One	22.0	19.8	18.3	17.7
Site Two	20.7	20.7	20.1	17.1
HMax (cm)				
Site One	2416	2278	2204	2105
Site Two	2359	2324	2287	2077
Dmax (cm)				
Site One	73	60	60	52
Site Two	72	61	60	51
b_2				
Site One	62.438	71.367	68.900	75.692
Site Two	61.722	71.705	71.667	76.078
b_3				
Site One	.42766	.59472	.57417	.72781
Site Two	.42863	.58775	.59722	.74587
G				
	200.78 (174.45,227.10)	139.23 (69.25,209.22)	112.92 (98.08,127.76)	133.47 (117.63,149.31)
Intertree Competition Component				
a	.0557 (.0443,.0671)	.0431 (.0150,.0712)	.1206 (.0919,.1493)	.0352 (.0290,.0414)

TABLE 2 Continued-

Coefficient	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
Site Physical, Chemical and Climatic Factor Component				
C_o	-3.32 (-12.75,6.31)	0	-47.28 (-35.02,-59.55)	-40.35 (-33.93,-46.77)
C_1	.-0045 (-.0056,.0034)	-.0025 (-.0044,-.0007)	.0356 (-.0429,-.0283)	.0890 (.0696,.1084)
C_2	.1081 (-.0514,.2671)	0	.3456 (.1429,.5503)	.1498 (.0695,.2302)
C_3	0	-37.26 (-56.11,-18.42)	0	12.71 (6.47,18.95)
Seasonal Growth Pattern Component				
d_1	809.67 (762.75,856.60)	725.75 (685.83,765.68)	713.97 (693.07,734.87)	761.11 (740.06,782.16)
d_2	1.4351 (1.3595,1.5107)	2.1470 (2.1132,2.7207)	2.2878 (2.1597,2.4159)	2.1322 (2.0256,2.2388)
d_3	-.5125 (-.7882,-.2367)	-.3278 (-.5708,-.0849)	0	-.5005 (-.7133,-.2876)

Table 3. Diameter growth model performance for each species when predicting total seasonal growth (sites and years combined).

Species	Proportion of Variation Explained[a/]	Average Residual (cm)	Standard Error of Residuals (cm)	$H_o: \mu_R=0$ $H_a: \mu_R\neq 0$
Northern Red Oak	0.443	0.0128 (6.4%)	.0079	NS
Paper Birch	0.724	0.0037 (6.1%)	.0075	NS
Aspen	0.286	0.0328 (16.9%)	.0105	p=0.01
Red Maple	0.512	0.0010 (1.0%)	.0041	NS

a/ Proportion of variation explained is calculated as follows:

$$PVE = \frac{\Sigma(Y_i-\bar{Y})^2 - \Sigma(Y_i-\hat{Y}_i)^2}{\Sigma(Y_i-\bar{Y})^2}$$

Table 4. Performance of the diameter growth model in predicting total seasonal growth by site and year for each species.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Northern Red Oak					
1	1986	61	-0.0069	0.0103	-0.0275, 0.0137
	1987	62	0.0135	0.0112	-0.0089, 0.0359
	1988	62	-0.0178	0.0113	-0.0414, 0.0048
2	1986	20	0.0204	0.0251	-0.0321, 0.0776
	1987	22	0.0797	0.0323	-0.0125, 0.1469
	1988	23	0.0250	0.0202	-0.0169, 0.0669
Paper Birch					
1	1986	10	0.0047	0.0162	-0.0139, 0.0413
	1987	10	0.0007	0.0086	-0.0188, 0.0202
	1988	10	0.0270	0.0270	-0.0200, 0.0740
2	1986	3	0.0191	0.0241	-0.0846, 0.1228
	1987	3	-0.0083	0.0153	-0.0711, 0.0605
	1988	3	-0.0048	0.0207	-0.0939, 0.0843
Aspen					
1	1986	30	0.0033	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	-0.0240, 0.0304
	1988	28	0.0533	0.0184	-0.0048, 0.0411
2	1986	11	0.0282	0.0193	-0.0143, 0.0707
	1987	11	0.0599	0.0227	0.0099, 0.1099
	1988	10	0.1175	0.0175	0.0779, 0.1571

Table 4, Continued.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Red Maple					
1	1986	10	0.0307	0.0143	-0.0016, 0.0630
	1987	10	0.0095	0.0129	-0.0197, 0.0387
	1988	10	-0.0852	0.0243	-0.1402,-0.0302
2	1986	70	-0.0019	0.0059	-0.0136, 0.0098
	1987	80	0.0002	0.0064	-0.0125, 0.0129
	1988	84	-0.0771	0.0053	-0.0876,-0.0666

Table 5. Average April-October weather conditions on the two study sites.

Variable	Site	Year 1986	1987	1988
Air Temperature (°C 2m Aboveground)				
	1	12.9	13.5	13.3
	2	12.0	12.7	12.5
Soil Temperature (°C at 5 cm Depth)				
	1	11.7	12.3	11.6
	2	11.2	11.8	11.2
Precipitation (cm)				
	1	36.6	53.4	44.7
	2	34.2	56.1	53.1
Relative Humidity (%)				
	1	-	70.0	62.5
	2	-	84.1	80.1
Soil Moisture (% at 5 cm)				
	1	14.1	10.9	10.6
	2	10.4	10.8	9.5

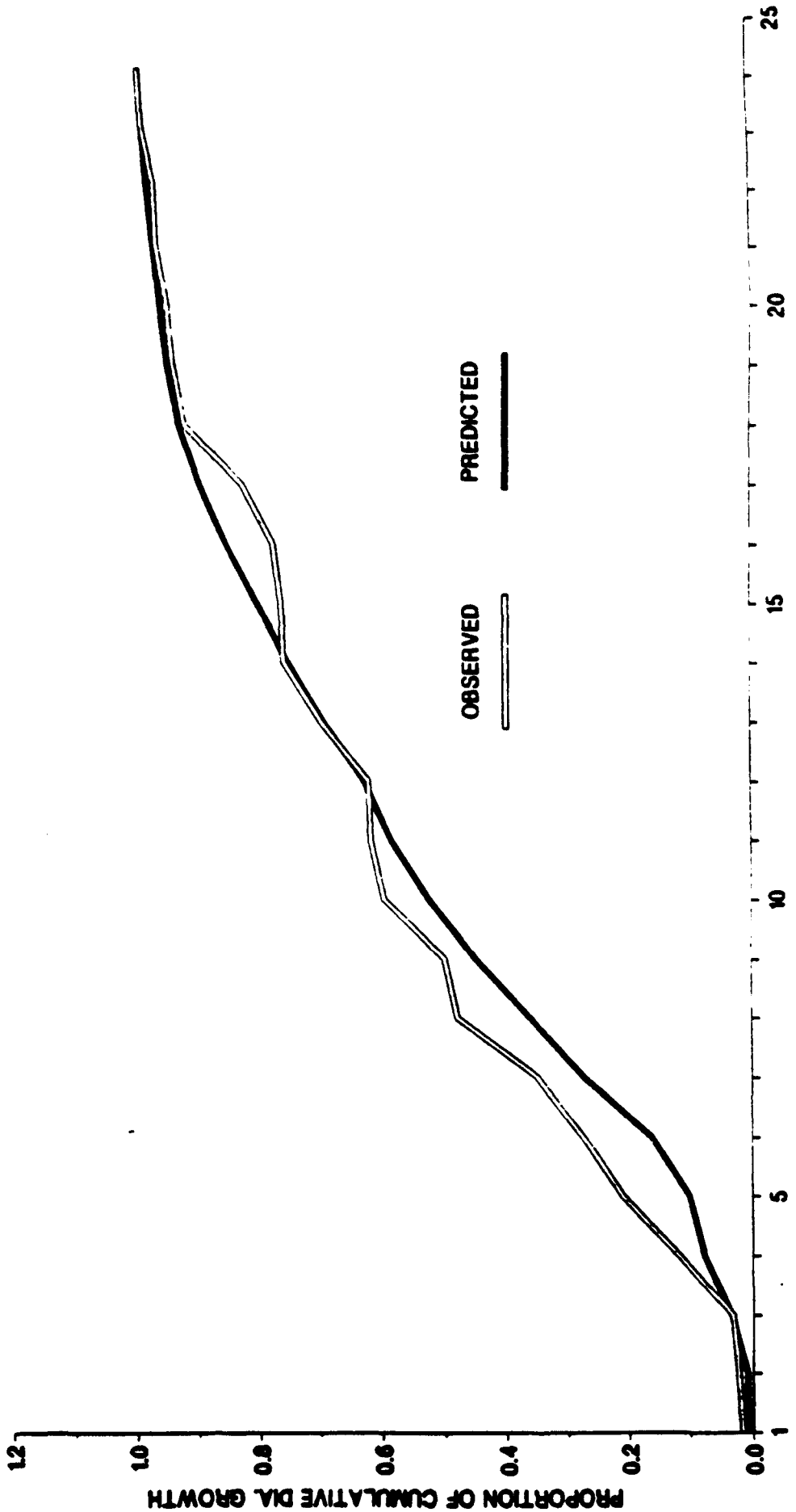

Figure 1. Observed and predicted seasonal growth patterns for northern red oak on Plot Two, Site Two in 1988.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: LITTER DECOMPOSITION AND MICROFLORA

The Michigan Study Site

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ABSTRACT

Seven full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed in the hardwood stand subunits at the control and antenna study sites, and in the red pine plantations at the control, antenna, and ground study sites. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and nutrient flux, and 2) bagged individual fascicle/leaf samples as well. The litter decomposition portion of this report focuses on analysis of the bulk litter sample data.

Precision in the annual raw data sets has generally been only slightly higher for the hardwood stand subunits than for the plantation subunits. For a variety of reasons, though, the hardwood stand subunits represent much more stable environments for making comparisons of decomposition mass loss among years than do the rapidly developing pine plantations. This is an especially important consideration with respect to our objective of detecting possible effects of increasing ELF electromagnetic field exposures.

Among the three study species, pine and oak have provided the most precise data. Bulk samples of each species lost approximately 25 percent and 33 percent of initial dry matter mass, respectively, during their first year on the forest floor in 1990-91. Individual pine fascicles also lose approximately 25 percent of initial mass. Data for individual oak leaves, which lost from 37 to 48 percent of initial mass, are only slightly less precise than bulk oak data; fragment loss from individual leaves is greater than from bulk samples, because the multi-layered bulk samples tend to trap a higher percentage of fragments. Bulk maple leaf data are the least precise, with

samples losing from 35 to 43 percent of initial mass. Because bulk and individual leaf samples decompose at very similar rates, and the detection limits associated with bulk leaf samples are adequate for detection of very subtle environmental perturbations of the litter decomposition process, we have decided not to continue study of individual leaf samples in FY92.

Two types of ANOVA model are being used currently to evaluate the generally significant year-by-site interactions. First, the traditional effects model ANOVA examines the data set for significant differences among years, sites, months, and plot nested within site, as well as for significant year-by-site interaction. Second, the mathematically equivalent means model ANOVA looks for significant differences among "siteyears" (e.g., control1985, antenna1985, ground1985, control1986, etc.). When significant differences exist among siteyears, multiple comparisons can be used to explain site trends among years. Our principle objective is to use ANACOV to explain these year-by-site interactions, using covariates unrelated to ELF field exposures if possible.

Covariates are proving useful for explaining differences detected by ANOVA in dry matter mass loss among hardwood stands, plantations, and years. An additional set of covariates has been developed, based on monthly (and seasonal) contributions of energy and moisture to the decomposition system. This set of covariates (e.g., degree days, total precipitation, and frequency of precipitation for each month or season) permits expression of the differential seasonal effects of energy inputs with respect to concurrent precipitation inputs. Covariates based on ELF EM field exposure data for 1985-1988 helped explain differences in mass loss progress among sites (for both hardwood stands and plantations) and among years (for hardwood stands), as well as the year-by-site interactions for both hardwood stands and

plantations. The newly developed covariates based on seasonal weather and retrieval dates, along with additional field data for the 1991-1993 operational years, appear to be capable of explaining differences in decomposition progress without ELF EM field exposure data.

Emphasis in the Red Pine Rhizosphere Streptomycete work element during 1991 was again focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings in the three plantations. Counts of both streptomycete levels and numbers of streptomycete morphotypes were made. Representatives of each morphotype were again characterized for ability to degrade complex organic compounds.

Seven full years (through 1991) of mycorrhizosphere streptomycete population dynamics data have been collected in all three study plantations. Though the 1991 raw data are presented in this report, data analysis (including the 1991 data) is incomplete, and therefore is not included in this report.

We propose to discontinue our mycorrhizosphere streptomycete studies for several reasons. In contrast to the litter decomposition and Armillaria root disease work elements, there is no indication of any ELF EM field effect on mycorrhizosphere streptomycete populations, through 1990. ANACOV has explained all differences among years and study plantations, as well as the year-by-site interaction, for both streptomycete levels (1986 - 1990) and morphotype numbers (1987 - 1990). It seems most appropriate to focus available resources toward explanation of the apparent possible relationships between ELF field exposure and rates of both litter decomposition and Armillaria root disease mortality.

Occasional problems with obtaining appropriate mycorrhiza samples in a timely manner, or with fungal contamination of samples, have also been a concern. These problems have frequently resulted in reduced sample sizes (which are already modest by design). This is not a problem with either the litter decomposition or the Armillaria root disease work elements.

The Armillaria root disease epidemics in all three plantations have been documented since their onset in 1986. Statistical analysis of the epidemics at each site has only become possible with the mapping of the entire seedling populations in early 1991. Discontinuation of the Armillaria root disease study from the Upland Flora Studies project has caused us to propose its adoption into the Litter Decomposition and Microflora project.

Armillaria root disease has killed between 1 and 33 percent of the red pine host populations in the plantations (depending on location), and there is good reason to expect that mortality will continue to occur. Documented Lake States epidemics of Armillaria root disease in red pine have peaked after 10 years of activity.

Armillaria root disease is easily diagnosed, permitting accurate mapping as the basis for statistical modeling. Sampling is accomplished by periodic 100 percent surveys of each plantation. Mapping data for the red pine populations and the spatial distribution of Armillaria clones in the plantations have become available for analysis only within the past year. It is now possible to model disease progress in the study plantations.

ANOVA has been used to compare the rates of disease progress in the three study plantations, based on the rate coefficients for the 12 quarter-plots comprising each plantation. Two more years of field study (1992-1993) would allow us to compare rate constants from pre- and post-operational years for each

plantation. Preliminary ANOVA results indicate that rates of disease progress are highest in the ground plantation and lowest in the control plantation, suggesting that ELF field exposure may enhance host vulnerability and/or pathogen virulence. We suspect that a combination of ANACOV and two more years of field data will explain the differences in rate of disease progress detected by ANOVA.

Historical (1986 to present) maps of the spatial distribution of the clones of Armillaria will permit modeling of the rate of disease progress based on the area occupied by each clone, rather than the arbitrarily designated 12 quarter-plots. It seems most appropriate, when comparing plantations, to base rates of disease progress on units of land area colonized by individual clones of the pathogen, rather than on units of land area only partially colonized by one or more clones.

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SUMMARY

Seven years of maple, oak, and pine leaf litter decomposition data have been collected at all study sites (through 1991). This work has spanned only two fully operational years.

Seven full years (through 1991) of mycorrhizosphere streptomycete population dynamics data have been collected in all three study plantations. However, limited availability of desirable covariate data restrict our use of analysis of covariance (ANACOV) to six years for streptomycete levels, and five years for morphotype numbers.

The ongoing Armillaria root disease epidemics in all three study pine plantations have been documented since their onset in 1986. Statistical analysis of the epidemics at each site has only become possible since early 1991, with the mapping of the entire seedling populations. Discontinuation of the Armillaria root disease study from the Upland Flora Studies project has caused us to propose its adoption into the Litter Decomposition and Microflora project.

All three work elements (litter decomposition, mycorrhizosphere streptomycetes, and root disease epidemiology) involve evaluation of potentially subtle ELF EM fields on the activities of communities of microorganisms. At least some of the fungal species involved in litter decomposition and root disease are represented by extremely long-lived, massive individual colonies, which have remarkable potential for vegetative spread. Field work must continue for an additional period of years during full antenna operation to provide sufficient data to evaluate the possibilities of ELF EM field effects on these aspects of forest health. However, due to 1) limited resources, 2) practical considerations of experimental design, and 3) the need to further study those elements which present preliminary evidence of possible ELF EM field effects, we are proposing to continue only

the litter decomposition and Armillaria root disease work elements.

The decision to continue data collection has been made based on the following criteria:

1. preliminary evidence in the current database suggesting possible ELF EM field effects on a response variable,
2. the detection limits of the measured variable; a value of less than 10 percent is considered desirable.

The following summarizes our findings to date for each work element and identifies the rationale for continuing efforts.

Element 1 Litter Decomposition

Red Pine Plantation and Hardwood Stand Study Sites

We propose to continue studying litter decomposition in both the plantations and hardwood stands. Hardwood stands and plantations present very different environments for decomposition. Detection limits for years and sites are very low in both types of study location. Changes in decomposition progress attributable to environmental differences among years and sites are being explained by ANACOV with increasing effectiveness.

Covariates based on ELF EM field exposure data for 1985-1988 helped explain differences in mass loss progress among sites (for both hardwood stands and plantations) and among years (for hardwood stands), as well as the year-by-site interactions for both hardwood stands and plantations. Recently developed covariates based on seasonal weather and retrieval dates, along with additional field data for the 1991-1993 operational years, appear capable of explaining differences in decomposition progress without ELF EM field exposure data.

Pine, Oak, and Maple Foliar Litter as Substrates

We propose to continue study of all three litter species used since 1985. These species differ dramatically in composition, each therefore favoring different components of the decomposer community. Hence, each species has a valuable role in testing for ELF EM field effects on litter decomposer communities.

Maple litter decays most rapidly, and provides the most variable data and the highest detection limits. Pine litter decays most slowly, and provides the least variable mass loss data and the lowest detection limits. Oak litter is intermediate in these regards. Nevertheless, detection limits for years and sites are very low for all three species. Some differences in decomposition progress among years and sites, and site-by-year interactions, remain to be explained by ANACOV.

Covariates based on ELF EM field exposure data helped explain differences in mass loss progress for all three litter species. We suspect that ANACOV, by using our new seasonal weather covariates, and with the addition of data for the operational years 1991-1993, may be able to explain these differences without using ELF EM field-related covariates.

Bulk Leaf vs. Individual Leaf Samples

Bulk and individual leaf samples decompose at very similar rates, and the detection limits associated with bulk leaf samples are adequate for detection of very subtle environmental perturbations of the litter decomposition process. Bulk samples also provide sufficient mass for nutrient analysis. Therefore, we have decided not to continue study of individual leaf samples in FY92.

Litter Nutrient Content

Nitrogen and phosphorus contents of retrieved litter samples, and

initial lignin content, have shown some value as covariates to explain differences among sites and/or site-by-year interactions. Therefore, we propose to continue these nutrient analyses.

Element 2 Mycorrhizoplane Streptomycetes

We propose to discontinue these studies for several reasons. In contrast to the litter decomposition and Armillaria root disease work elements, there is no indication of any ELF EM field effect on mycorrhizosphere streptomycete populations, through 1990. ANACOV has explained all differences among years and study plantations, as well as the year-by-site interaction, for both streptomycete levels (1986 - 1990) and morphotype numbers (1987 - 1990). It seems most appropriate to focus available resources toward explanation of the apparent possible relationships between ELF field exposure and rates of both litter decomposition and Armillaria root disease mortality.

Occasional problems with obtaining appropriate mycorrhiza samples in a timely manner, or with fungal contamination of samples, are also a concern. These problems have frequently resulted in reduced sample sizes (which are already modest by design). This is not a problem with either the litter decomposition or the Armillaria root disease work elements.

Element 3 Armillaria Root Disease Epidemiology

The association between Armillaria root disease severity and host stress is well documented. Various stresses (perhaps including ELF EM fields) predispose conifers to successful infection by the virulent A. ostoyae. Armillaria root disease has killed between 1 and 33 percent of the red pine host population in the study plantations (depending on location), and there is good reason to expect that root disease mortality will continue to occur. Documented Lake States epidemics of Armillaria root disease in red pine have peaked after 10 years of activity.

Armillaria root disease is easily diagnosed, so its progress can be accurately mapped and statistically modeled. The fact that sampling is accomplished by periodic 100 percent surveys of each study plantation represents another advantage of this work element. Mapping data for 1) the red pine host populations, 2) the historical spatial distribution of Armillaria clones in the plantations, and 3) ELF EM field strengths all have become available for analysis only within the past year.

Mapping of Root Disease Mortality

Because of the uneven distributions of these host populations in each plantation, all living red pine seedlings in the three study plantations were tagged and mapped in early 1991. Because all red pine mortality since 1986 (the first incidence of Armillaria root disease mortality) has also been mapped, it is now possible to model disease progress in the study plantations. ANOVA has been used to compare the rates of disease progress in the three study plantations, based on the rate coefficients for the 12 quarter-plots comprising each plantation. Two more years of field study (1992-1993) would allow us to compare rate constants from pre- and post-operational years for each plantation.

Preliminary ANOVA results indicate that rates of disease progress are highest in the ground plantation and lowest in the control plantation, suggesting that ELF field exposure may enhance host vulnerability and/or pathogen virulence. We propose to continue this effort, and suspect that a combination of ANACOV and two more years of field data will explain the differences in rate of disease progress detected by ANOVA.

Mapping Spatial Distributions of Armillaria Species and Clones

The pathogen is isolated into pure culture from seedling mortality and Armillaria mushrooms. These isolates are mapped

and identified to vegetative individuals (clones) and to species. So far, all clones responsible for red pine mortality in the study plantations belong to A. ostoyae. Clones of A. gallica are also widespread, but are not pathogenic to red pine.

Historical (1986 to present) maps of the spatial distribution of the clones of A. ostoyae will permit modeling of the rate of disease progress based on the area occupied by each clone, rather than the arbitrarily designated 12 quarter-plots. We propose to continue this effort, because it seems appropriate, when comparing plantations, to base rates of disease progress on units of land area colonized by individual clones of the pathogen, rather than on units of land area only partially colonized by one or more clones.

INTRODUCTION

Background

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF EM fields cause fundamental changes in forest health. This research program includes two separate yet highly integrated projects, the Upland Flora Studies project and the Litter Decomposition and Microflora project. Work elements of the Litter Decomposition and Microflora project examining 1) rates of litter decomposition in both hardwood stands and red pine plantations, 2) mycorrhizoplane streptomycete population dynamics on red pine plantation seedlings, and 3) Armillaria root disease epidemiology in the red pine plantations share the same field sites with the Upland Flora Studies project. In fact, the Armillaria root disease work element is adopted from the Upland Flora Studies project. These three work elements complement and extend the program of the Upland Flora Studies project. The information obtained will be used for comparison of pre-operational and operational status of the study variables, to evaluate possible ELF EM field effects on the local forest ecosystem.

We believe that the research programs representing all three work elements are biologically and statistically defensible. However, the litter decomposition and Armillaria root disease studies have each provided preliminary evidence of possible ELF EM field effects, whereas the mycorrhizoplane streptomycete studies have not (through 1990). Unfortunately, financial constraints necessitate the discontinuation of one of these work elements, and we propose that the mycorrhizoplane streptomycete studies be concluded in FY92. This Technical Summary and Proposal examines the degree of success achieved by research in all three work elements to date, and outlines plans for conclusion of the litter decomposition and Armillaria root disease work elements in 1994.

Objectives

The overall objectives of these work elements are to determine the impacts of ELF EM fields on:

1) rates of litter decomposition for three important local tree species (red maple, northern red oak, and red pine),

2) overall levels and taxonomic richness of mycorrhizoplane streptomycete populations, and

3) rates of Armillaria root disease progress in red pine plantations.

Ultimately, the question of whether ELF EM fields impact these segments of forest communities will be answered by testing various hypotheses (Table 1) based on the results of relatively long-term studies.

Table 1. Critical null hypotheses which will be tested to fulfill objectives of the ELF environmental monitoring program Litter Decomposition and Microflora project.

I.	There is no difference in the level of foliar litter decomposition (dry matter mass loss) achieved, or the seasonal pattern by which it proceeds, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.
II.	There is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations on the plantation red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.
III.	There is no difference in the representation of different identifiable strains of mycorrhizoplane streptomycetes on the plantation red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.
IV.	There is no difference in the rate of Armillaria root disease progress in the study red pine plantations that cannot be explained using factors unaffected by ELF antenna operation.

PROJECT DESIGN

Overview of Experimental Design

Emphasis has been placed on development of a statistically rigorous experimental design capable of separating potentially subtle ELF EM field effects from the natural variability associated with soil, vegetational, climatic and temporal factors. Consequently, in order to most effectively test our hypotheses, we have fully integrated our studies into those of the Upland Flora Studies project, permitting us to take full advantage of both that project's basic field design and the extensive data collected by that project on the tree, stand and site factors which influence or regulate the processes and populations we are measuring (Table 2). The measurements made and the associated analyses are discussed more thoroughly in the following sections. The experimental designs integrate direct measures with site variables, and are a common thread through the work elements of both projects due to shared components of the field design.

Because of the similarity in analyses, an understanding of this experimental design is essential. However, the rationale and progress for measurements in each work element of this study are necessarily unique and will be discussed separately in the following sections.

Experimental Design and Electromagnetic Exposure

The EM fields associated with the ELF system are different at the antenna and ground locations. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at a ground terminal, and at a control location some distance from the antenna. IITRI has measured 76 hz electric field intensities at the three study sites since 1986 when antenna testing began; background 60 hz field intensities were

measured at all sites in 1985. Three types of EM field are measured: magnetic (mG), longitudinal (mV/m), and transverse (V/m).

The most general experimental design for the Upland Flora Studies project is a split-plot in space and time. Each site (control, antenna, and ground) is subjected to a regime of ELF field exposures and is subdivided into two stand types: pole-sized hardwood stands and red pine (Pinus resinosa Ait.) plantations. Both stand types at each field site are divided into three contiguous plots to control variation. The time factor is the number of years in which the experiment is conducted for pre-operational and operational comparisons, or the number of sampling periods in one season for year to year comparisons. It is necessary to account for time since successive measurements are made on the same whole units over a long period of time without re-randomization. A combined analysis involving a split-plot in space and time is made to determine both the average treatment response (site difference) over all years, and the consistency of such responses from year to year.

Each site follows this design with one exception. There is no pole-sized hardwood stand type at the ground unit, because the necessary buffer strips would have placed the hardwood stand type too far from the grounded antenna for meaningful exposure. Thus one treatment factor (hardwood stands) is eliminated at the ground site. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. Where analyses are conducted on only one stand type, the stand type treatment factor is irrelevant and is not included in the analysis. This is the case for all studies of the Litter Decomposition and Microflora project. All other factors remain unchanged.

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Litter Decomposition and Microflora project, the objective each group of measurements relates to, and the work elements which address the necessary measurements and analyses.

Hypothesis Number	Related Objective	Measurements	Work Elements
I	1	**Monthly determinations of dry matter loss, from bulk leaf litter samples of maple, oak, and pine** [2]; climatic and biotic variables, litter nutrient and lignin contents	1,(1),(5)[1]
II	2	**Monthly counts of streptomycetes associated with Type 3 red pine seedling mycorrhizae;** climatic variables, mycorrhizosphere pH	2,(1)
III	2	**Monthly counts of numbers of streptomycete morphotypes associated with Type 3 red pine seedling mycorrhizae;** climatic variables, sample processing delay	2,(1)
IV	3	**Monthly mapping and identification of Armillaria cultures isolated from red pine seedling mortality;** climatic variables, ELF EM field strength, seedling size, hardwood stump population characteristics	3,(1),(2)

[1] Numbers in parentheses refer to work elements in the Upland Flora Studies project.

[2] Bold print designates the response variable; other variables listed are covariates.

Analysis of Covariance

Analysis of variance (ANOVA) and analysis of covariance (ANACOV) are used in our studies to determine effects of treatments on decomposition progress, streptomycete population levels and morphotype numbers, and rates of Armillaria root disease progress. Treatments in the case of litter decomposition include year, individual plantation or hardwood stand, monthly sampling date, and ELF EM field exposure. For streptomycete population dynamics, treatments include year, plantation, and monthly sampling date. For rate of root disease progress, the only treatment is the individual plantation. The statistical design employed for all three work elements reported here is a factorial design with blocking and covariates. The factors included in the design vary somewhat by experiment. They include year, month, site, and blocking for the litter decomposition and streptomycete studies. Site and blocking (see below) are the only factors included in the design for root disease study. In this special case, time is accounted for in calculating the rate constant. In the litter decomposition work element, separate analyses are conducted for the hardwood and pine plantation stand types, to satisfy the assumptions required by the ANOVA and ANACOV models.

The experiments conducted in the Litter Decomposition and Microflora project are not split-plot experiments across time, a design frequently used in the Upland Flora Studies project. A split-plot design across time requires repeated measurements on the same experimental unit. In contrast, the experimental units in the litter decomposition and streptomycete work elements are destructively sampled to obtain the required measurements; the experimental units in the root disease work element are the 12 quarterplots which comprise each plantation. Additional future root disease models will use individual Armillaria clones as the experimental units.

Blocking is employed to control variability. In the root disease

models, for example, the three plots comprising each plantation are blocks, and each contains four quarter-plot experimental units. The blocking employed produces an unbalanced incomplete block design (i.e., not all ELF treatments can be represented in each block). The incomplete block design is dictated by the spatial separation of the ELF treatments.

Our experimental design directly controls experimental error to increase precision. Indirect or statistical control can also reduce variability and remove potential sources of bias through the use of covariate analysis. This involves the use of variables (covariates) which are related to the variable of interest (variate). Covariate analysis removes the effects of an environmental source of variation that would either inflate the experimental error or inappropriately increase the variability explained by the treatments. Identification of covariates which are both biologically meaningful and independent of treatment effects is one of the most important steps in our current analysis. Covariates will have to be shown to be unaffected (both directly and indirectly) by ELF EM fields before they can be legitimately used to explain (with respect to ELF EM fields) any non-ELF-induced differences in response variables between years or sites. The independence of the ambient conditions covariates will be tested by the Upland Flora Studies project.

Covariates under examination differ among the dependent variables considered (Table 2). For the 1990 Annual Report, most analyses used climatic variables computed from weather data, such as actual evapotranspiration or running totals of air or soil temperature degree days, total precipitation, and/or the number of precipitation events. Other covariates in the analysis of decomposition progress included litter nitrogen, phosphorus, and lignin contents. Most recently, we have developed a set of seasonal cumulative (rather than annual cumulative) weather-related covariates which better reflect the seasonal interaction between energy and moisture inputs to the

decomposition process. We have also developed another effective covariate for the decomposition studies, consisting of the deviation (in days) between a standard set of retrieval dates and each actual retrieval date. Analyses will be conducted to determine which of these are both biologically meaningful and statistically significant without violating the necessary assumptions required for ANACOV.

The adjusted treatment means presented for each ANACOV model employ the arc sin square root transformation of raw data (litter decomposition, as dry matter mass loss), the log10 transformation of raw data (streptomycete levels and morphotype numbers), or the raw data itself (Armillaria root disease progress rate). The adjusted treatment means are adjusted for the covariate(s) used, and represent the transformed data after the treatment means have been adjusted for the effect of the covariate(s). Throughout the ANACOV discussion, differences detected between means are <u>after</u> the effect of the covariate(s) has been considered. Thus, for example, when it is stated that decomposition failed to progress during a given month, the interpretation should be that the covariate(s) adequately explained any change that may have occurred during that month.

<u>Testing for ELF EM Field Effects</u>

ELF EM field intensities appear to be affected by vegetative and soil factors. Also, timing and intensity of ELF EM field treatments have varied through various phases of antenna testing prior to full antenna operation. The antenna was activated for low-level intermittent testing during the 1987 and 1988 growing seasons, and achieved fully operational status late in 1989. Therefore, hypothesis testing examines differences in response variables between fully operational years vs. intermittent testing years vs. pre-operational years, and also between antenna, ground, and control sites within years.

In the litter decomposition study, ANACOV models nearly always indicate significant site-by-year interactions. Furthermore, these interactions are highly significant. The interpretation of the site-by-year interaction is that the year must be known to predict the site effect, and conversely the site must be known to predict the year effect. In this case, explaining the main effect of year or site does not necessarily indicate that no ELF EM field effect is occurring. Furthermore, it can be hard to interpret the interaction term to understand if the effect follows the same pattern as the ELF EM field exposure, or if it is only random variation due to microclimatic factors not represented in the analysis.

An alternative ANACOV model, the means model, can be formulated to address this problem. In this representation, each combination of the factor levels is included as a separate treatment. Thus, the two treatments and the interaction term are combined into one treatment, which we call Siteyear; individual treatment levels could include Antenna-1985, Antenna-1986, ... , Antenna-1991, Ground-1985, Ground-1986, ... , Ground-1991, Control-1985, Control-1986, ..., and Control-1991. This approach is mathematically equivalent to the effects model, but it allows more detailed analysis of the treatment combinations. The means model was demonstrated in the Annual Report 1990 (pages 33-36), using the bulk pine experiment. The means model allows us to analyze the information at a much more disaggregated level than does the effects model.

Detection Limits and Statistical Power

Each study in the Litter Decomposition and Microflora project is reviewed in this proposal for continuation. Each study has been peer reviewed. We feel that the biological basis of each is sound and will contribute to the overall objective of determining whether forest health is affected by ELF EM field exposure. Because of the variability inherent in ecosystem studies, coupled

with the expected subtle nature of any perturbations due to ELF EM field exposure, a quantitative assessment of the level of precision achieved by each study is central to discussions of proposed continuation. Two different measures were considered to make this evaluation: statistical power and detection limits. Power is defined as the likelihood that a particular statistical test will lead to rejection of the null hypothesis if the null hypothesis is false. Exact calculation of power requires knowledge of the alpha level (Type I error), parameters of the distribution of the variable of interest under the null hypothesis, and the specification of a given alternative parameter value. In a t-test, for example, to determine power one must know the alpha level (commonly 0.05), the value of the test statistic under the null hypothesis (zero if the test is to determine whether two means are different), and the degree of difference in the means which is considered biologically important (e.g., 10 percent difference). The latter value is difficult for scientists to agree upon in ecological studies, because it is often a matter of judgement. Quantitative knowledge of ecological relationships is often poor, and certain knowledge may be lacking (e.g., whether a ten percent difference in a parameter is important where a five percent difference is not). While it is possible to construct curves showing power for a number of alternative hypotheses, one is still left with the question of how much of a difference is important.

An alternative procedure is the a posteriori calculation of the detection limit (e.g., the degree of difference which leads to 50 percent chance of correctly rejecting the null hypothesis for a given alpha level). Use of the detection limit allows reviewers to evaluate the test in light of their own views of what degree of difference is important. A detection limit is not exact, since it is an a posteriori test, depending on the data used in the test procedure and the procedure itself. The detection limits presented in this technical summary and proposal were calculated from the results of ANACOV models and the least

square means procedure employed by the SAS Proc GLM software.

In summary, calculation of statistical power has the advantage of being exact, but the disadvantage for ecological studies of requiring specification of the degree of change considered important. The calculation of detection limits has the advantage of not requiring specification of an alternative (power is fixed at 50 percent), but the disadvantage of being an a posteriori calculation, and therefore not exact. We feel that the detection limit provides information similar to statistical power, but more suitable for ecological studies, since specification of an exact alternative hypothesis is not required.

This continuation proposal outlines the degree of success achieved by past Litter Decomposition and Microflora project research efforts and the Armillaria root disease studies adopted from the Upland Flora Studies project. Proposed continuation of data collection through 1993 and culmination of the project in 1994 are based on the biological significance and precision of measurement of these studies.

WORK ELEMENTS

The work elements of the Litter Decomposition and Microflora project acknowledge the two diverse study areas included within this project. Data from several work elements of the "Trees" project are used to test each hypothesis posed by this project (Table 2). The following sections present a synopsis of the rationale for study, measures, and analyses conducted in each work element of this project.

ELEMENT 1: LITTER DECOMPOSITION AND NUTRIENT FLUX

Introduction

The litter decomposition subsystem of any ecosystem serves to 1) pool the nutrients relinquished by primary producers, 2) transform the essential nutrients remaining in litter or trapped by it into forms available for root uptake, and 3) release these nutrients in a regulated fashion for re-use by the autotrophs. The energy provided by litter decomposition also fuels heterotrophic dinitrogen fixation and the capture of nutrients washed from the atmosphere or leached from living plants. Due to the large quantities of potentially available plant nutrients found in the litter component of forest biomass, knowledge of key decomposition processes and their rates is essential to conceptualization of ecosystem dynamics.

Organic matter decomposition is primarily accomplished by microorganisms, whose activities are regulated by the environment. Environmental factors which disrupt decomposition processes detract from the orderly flow of nutrients to vegetation. As a new and anthropogenic environmental factor, ELF EM fields merit investigation for possible effects on the litter decomposition subsystem.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar 1978). Conversely, dry matter mass loss and nutrient flux are useful measures of the impact of environmental perturbations on the integrated activities of the litter biota. The methods employed in these studies integrate the activities of all but the largest soil fauna, and ELF fields represent one possible cause of environmental perturbation.

Studies of litter decomposition and associated nutrient flux also extend the usefulness of litter production data collected in the

course of forest vegetation studies. Knowledge of litter biomass production and nutrient content provide one link between the overstory and forest floor components of the forest ecosystem.

The forest vegetation at all three study sites is classified in the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983). The two hardwood species selected for study, northern red oak (Quercus rubra) and red maple (Acer rubrum), are common to both of the hardwood stand subunits. Red pine (Pinus resinosa) was selected as the conifer species for study because 1) it exists as scattered mature specimens throughout the area, and 2) the study plantations were established with red pine. These three study species represent a range of decomposition strategies and rates.

Seven full years of maple, oak, and pine leaf litter decomposition study have been completed at the ground, antenna, and control study sites. The litter decomposition study element involves evaluation of the potential for subtle ELF EM field effects on the activities of communities of interacting microorganisms. Underway since 1985, this work has spanned two pre-operational years and three years of intermittent antenna testing, but only two fully operational years. Field work must continue for an additional period of years during full antenna operation to provide sufficient data to evaluate the possibility of ELF EM field effects on these aspects of forest health.

The decision to continue data collection for the litter decomposition work element is based on the following criteria:

1. evidence in the current database suggesting possible ELF EM field effects on the response variable, and
2. subtle changes in decomposition rate can be detected (generally, detection limits below ten percent suggest sufficient precision to detect subtle responses to ELF EM field effects).

Methods

Litter decomposition is being quantified as percent change over time in dry matter mass. Loss of dry matter mass over time from freshly fallen foliar litter samples has been widely used as a measure of fully integrated litter decomposition (Kendrick 1959, Jensen 1974, Millar 1974, Witkamp and Ausmus 1976, Fogel and Cromack 1978). Experiments in this project are conducted annually and focus on the year following each year's autumn litterfall. Bagged bulk foliage samples of each litter species for the eighth complete study have been installed in the field.

A single parent litter collection, from a single location, is made for each study species in order to avoid the effects of possible differences in substrate quality associated with geographically different litter sources. Ratios of fresh to dry matter mass and initial nutrient content are determined for random samples taken at regular intervals during field sample preparation from each of the annual pine, oak, and maple litter parent collections. All mass loss data (dry matter as well as nutrient masses) are based on 30°C dry masses. Samples destined for the field are pre-weighed and enclosed in nylon mesh envelopes (3 mm openings) constructed to lie flat on the ground.

Dry matter mass loss has been studied (through 1991) by an individual fascicle/leaf method as well as via bulk litter samples. Nutrient flux can be determined only for the bulk litter samples. Individual fascicles/leaves offer the opportunity to study decomposition of basic foliage units. Each individual fascicle or leaf is completely intact at the time of disbursal. The influence of fragmentation on individual pine fascicle decomposition is especially easy to eliminate by discarding any fascicles broken during the course of study. Individual leaf density (g cm^{-1}) is determined for each individual oak leaf, for use as a covariate.

All samples are disbursed in the field during early December, and subsets are retrieved at approximately monthly intervals from early May to early November. Snow cover at the study sites dictates the earliest and latest possible recovery dates from the plantation subunits. The experimental design regarding bulk litter envelopes remains unaltered. Two clusters of envelopes are placed on each of the three plots comprising each plantation and hardwood stand type. One envelope per species is retrieved each month from each of these 6 clusters.

Raw data are expressed as the proportion (X) of original dry matter mass remaining over time. Sufficient samples are recovered each month to permit analysis of differences in dry matter losses between sites, years, and monthly sampling dates by ANOVA and ANACOV. Dry matter mass loss data are transformed to the arc sin square root of X, to homogenize variances prior to correlation analysis, ANOVA, and ANACOV (Steel and Torrie 1980).

Throughout the study, all bulk litter samples have been either ground for nutrient analysis or archived for possible future nutrient analysis. The residual portion of every ground sample, beyond the portion required for nutrient analysis, has been archived for future reference. The residual portions of the autumn, 1988-1990, parent litter collections have also been archived to permit establishment of a future decomposition experiment, for comparison of decomposition of samples derived from litter collected during different years. This experiment would afford an opportunity to determine whether or not source litter quality variables could be responsible for any unexplained differences which remain among our annual experiments.

We will continue to fully analyze the bulk standard samples representing the parent litter collections. We will also continue to archive all bulk samples retrieved from the field. However, we have suspended nutrient analysis of retrieved samples, in order to devote available resources to mass loss

studies.

All ANOVAs and ANACOVs have been conducted on the mainframe computer, using PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985). In all statistical analyses, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$, regardless of the statistical test employed. Multiple range comparisons among significant differences detected by ANOVA and ANACOV are being identified by the Least Square Means pairwise comparison option, within PROC GLM.

The almost uniformly significant year-by-site interactions are especially interesting, because they may indicate an ELF effect on decomposition rate. In order to explain significant year-by-site interactions, two types of ANOVA model have been used. First, the traditional effects model ANOVA examines the data set for significant differences among years, sites, and months, as well as for significant year-by-site interaction. Second, the mathematically equivalent means model ANOVA looks for significant differences among "siteyears" (e.g., control1985, antenna1985, ground1985, control1986, etc.). When significant differences exist among siteyears, multiple comparisons can be used to explain site trends among years. Our principle objective is to use ANACOV to explain these year-by-site interactions, using covariates unrelated to ELF field exposures if possible.

Covariates are proving useful for explaining differences detected by ANOVA among hardwood stands, plantations, and years, as well as for explaining the generally significant year-by-site interactions. Preliminarily useful covariates so far have included actual evapotranspiration (AET), total precipitation, precipitation event frequency, air and soil temperature degree days, initial lignin content, and percents nitrogen and phosphorus content on retrieval. We feel certain that ANACOV will become increasingly effective as our understanding of the decomposition process in the ELF study area ecosystem allows us

to design more appropriate covariates.

We have also considered several ANACOV models whereby 76 Hz and/or 60 Hz electromagnetic field exposures contributed (along with other covariates that are not affected by ELF EM fields) toward accounting for more differences among years, sites, and year-by-site interactions than did other groups of covariates without electromagnetic field exposure variables. We are concerned about the appropriateness of including electromagnetic field strength variables in our ANACOV models. It seems possible that they may behave largely as categorical variables in apparently explaining differences among years and sites (and year-by-site interaction), especially considering the relatively small number of years included in the analysis so far. Also, the P values achieved by all four electromagnetic field strength variables (L60, L76, M76, and T76) are very high, raising questions about the nature of their contributions to a real explanation of year and site differences. In this regard, however, AET, PCN and PCP also have high P values in a number of interesting models.

To improve the effectiveness of our covariate analysis, we have recently developed additional sets of covariates, based on seasonal contributions of energy and moisture to the decomposition system (spring: through early June; summer: early June through early September; autumn: early September through early November). This approach addresses the basic nonlinearity of litter decomposition progress at the ELF study sites. These sets of covariates (i.e., for each season: for degree days, total precipitation, and frequency of precipitation) should permit expression of the differential seasonal effects of energy inputs with respect to concurrent precipitation inputs.

We have also developed covariates to account for different dates of sample retrieval across years. These covariates also account for differing decomposition rates among months within a year.

For each litterbag, the variable "deviation" is defined as the difference (in days) between its actual retrieval date and the corresponding date in a set of arbitrarily established monthly target retrieval dates. A separate regression coefficient for the deviation variable is estimated for each month.

1990-91 Study

Fresh-fallen red pine litter was again collected on nylon netting spread in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its remoteness from interfering ELF (76 Hz) electromagnetic fields. Fresh-fallen red maple litter was again collected near the Covered Drive, seven miles from Houghton, for the same reasons. Northern red oak litter was again collected near the northeast edge of the control plantation subunit plot 3.

Bulk pine sample envelopes measured 22 cm x 28 cm; each contained 10 g (air dry mass) of the parent collection. Bulk maple and oak sample envelopes measured 44 cm x 28 cm; each contained 15 g (air dry mass) of the parent collection. Individual leaf envelopes measured 22 cm x 28 cm, and each contained one pine fascicle and one oak leaf.

Prior to the 1986-87 study, individual leaf envelopes contained multiple tethered leaves of a single species, and one envelope per month per species was recovered from each plantation or hardwood stand subunit plot. Beginning with the 1987 field season, we collected 1 envelope (containing one pine fascicle and one oak leaf) from each of 8 locations per plot each month. As a result, the individual study leaves of each species are more clearly independent of one another, and recovery of individual leaf envelopes from 24 locations per plantation or hardwood stand (instead of 3) better represents site variability.

The experimental design regarding bulk litter envelopes remains

unaltered. Ten bulk litter envelopes of each species were placed together at two locations on each of the three plots comprising each subunit. One bulk envelope per species was retrieved each month from each of these 6 locations per subunit.

1991-92 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter were collected again in 1991 as described for the 1990-91 study. The same experimental design established for the 1984-85 through 1990-91 studies is being followed for bulk litter samples in the 1991-92 study. Individual fascicle/leaf studies have been discontinued.

Description of Progress

1990-91 Study

Tables 1.1 and 1.2 present mean dry matter mass loss summaries (raw, untransformed data) for the bulk and individual fascicle pine samples retrieved in 1991 (by sampling date, site and stand type), along with standard deviations and minimum detectable differences (based on 95 percent confidence intervals for sample means). Tables 1.3 and 1.4 present the corresponding data from all five study sites and stand types for bulk and individual oak leaf samples. Corresponding data for bulk maple samples are presented in Table 1.5. The data show that the following shifts in bulk and individual fascicle/leaf sample means should be detectable ($\alpha = 0.05$).

A. Pine
   1. Plantation Subunits
      a. Individual Fascicles - 3%
      b. Bulk Samples - 4%
   2. Hardwood Stand Subunits
      a. Individual Fascicles - 2%
      b. Bulk Samples - 3%

B. Oak
   1. Plantation Subunits
      a. Individual Leaves - 7%
      b. Bulk Samples - 7%
   2. Hardwood Stand Subunits
      a. Individual Leaves - 6%
      b. Bulk Samples - 7%

C. Maple
   1. Plantation Subunits
      a. Bulk Samples - 11%
   2. Hardwood Stand Subunits
      a. Bulk Samples - 8%

Table 1.1. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1991, for bulk red pine foliar litter samples disbursed in early December, 1990.

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Unit: Hardwood Stand Mean	S.D.	%
6 May	0.93	0.02	3	0.93	0.01	1
3 June	0.89	0.02	2	0.89	0.02	2
2 July	0.86	0.02	2	0.85	0.02	2
4 August	0.81	0.01	2	0.79	0.02	3
1 September	0.79	0.02	3	0.76	0.02	3
6 October	0.75	0.02	2	0.75	0.01	1
19 November	0.74	0.02	3	0.73	0.01	2

Table 1.1. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D.	%	Control Unit: Hardwood Stand Mean	S.D.	%
6 May	0.92	0.01	2	0.94	0.01	1
3 June	0.89	0.01	1	0.91	0.01	2
2 July	0.86	0.02	2	0.87	0.01	2
4 August	0.82	0.02	3	0.82	0.03	3
1 September	0.78	0.02	3	0.78	0.01	1
6 October	0.75	0.01	2	0.75	0.01	2
19 November	0.74	0.03	4	0.74	0.02	2

Table 1.1. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
6 May	0.93	0.01	1
3 June	0.89	0.02	3
2 July	0.86	0.02	2
4 August	0.83	0.01	1
1 September	0.79	0.02	3
6 October	0.77	0.02	2
19 November	0.75	0.01	2

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 1.2. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1991, for individual red pine fascicles disbursed in early December, 1990.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
6 May	0.92	0.03	1	0.93	0.02	1
3 June	0.90	0.02	1	0.90	0.02	1
2 July	0.84	0.03	2	0.85	0.04	2
4 August	0.81	0.02	1	0.81	0.03	2
1 September	0.78	0.03	2	0.79	0.04	2
6 October	0.75	0.04	3	0.75	0.03	2
19 November	0.74	0.03	2	0.73	0.04	2

Table 1.2. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.95	0.02	1	0.95	0.02	1
3 June	0.90	0.02	1	0.91	0.02	1
2 July	0.85	0.03	1	0.88	0.02	1
4 August	0.80	0.04	2	0.81	0.04	2
1 September	0.77	0.03	2	0.80	0.02	1
6 October	0.73	0.04	2	0.76	0.04	2
19 November	0.74	0.04	3	0.75	0.02	1

Table 1.2. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.93	0.02	1
3 June	0.90	0.03	1
2 July	0.84	0.04	2
4 August	0.81	0.03	2
1 September	0.78	0.04	2
6 October	0.74	0.03	2
19 November	0.74	0.05	3

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 1.3. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1991, for bulk northern red oak foliar litter samples disbursed in early December, 1990.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
6 May	0.93	0.01	2	0.93	0.01	1
3 June	0.88	0.02	3	0.88	0.02	2
2 July	0.83	0.03	4	0.82	0.02	2
4 August	0.78	0.01	2	0.77	0.01	1
1 September	0.75	0.02	2	0.73	0.02	3
6 October	0.70	0.04	5	0.64	0.04	7
19 November	0.67	0.01	2	0.61	0.01	2

Table 1.3. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.92	0.01	1	0.93	0.03	3
3 June	0.88	0.01	1	0.87	0.01	2
2 July	0.83	0.04	5	0.82	0.02	2
4 August	0.79	0.02	3	0.79	0.02	2
1 September	0.74	0.02	2	0.73	0.03	5
6 October	0.67	0.03	4	0.68	0.03	5
19 November	0.66	0.04	7	0.65	0.03	5

Table 1.3. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.92	0.02	2
3 June	0.87	0.01	1
2 July	0.82	0.02	2
4 August	0.78	0.02	2
1 September	0.75	0.02	3
6 October	0.68	0.04	6
19 November	0.66	0.03	5

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 1.4. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1991, for individual northern red oak leaves disbursed in early December, 1990.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
6 May	0.89	0.04	2	0.90	0.04	2
3 June	0.81	0.06	3	0.86	0.04	2
2 July	0.73	0.09	5	0.81	0.07	3
4 August	0.68	0.10	6	0.76	0.05	3
1 September	0.64	0.10	7	0.70	0.07	4
6 October	0.60	0.09	6	0.66	0.06	4
19 November	0.53	0.09	7	0.59	0.07	5

Table 1.4. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.90	0.04	2	0.90	0.04	2
3 June	0.82	0.06	3	0.85	0.04	2
2 July	0.76	0.07	4	0.79	0.05	3
4 August	0.73	0.07	4	0.75	0.06	4
1 September	0.67	0.09	6	0.71	0.05	3
6 October	0.61	0.09	6	0.60	0.08	6
19 November	0.58	0.10	7	0.63	0.09	6

Table 1.4. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.90	0.03	2
3 June	0.81	0.06	3
2 July	0.73	0.08	5
4 August	0.68	0.07	4
1 September	0.63	0.10	7
6 October	0.57	0.10	7
19 November	0.52	0.11	9

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 1.5. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1991, for bulk red maple foliar litter samples disbursed in early December, 1990.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
6 May	0.83	0.03	4	0.82	0.02	3
3 June	0.76	0.03	4	0.76	0.02	3
2 July	0.73	0.04	5	0.75	0.05	7
4 August	0.68	0.03	5	0.72	0.05	7
1 September	0.65	0.02	4	0.66	0.03	5
6 October	0.63	0.02	4	0.66	0.04	7
19 November	0.60	0.03	5	0.65	0.05	8

Table 1.5. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
6 May	0.81	0.01	2	0.81	0.02	3
3 June	0.77	0.04	5	0.76	0.02	3
2 July	0.73	0.03	4	0.76	0.04	5
4 August	0.71	0.04	6	0.70	0.02	3
1 September	0.65	0.03	5	0.66	0.02	4
6 October	0.64	0.06	9	0.62	0.03	5
19 November	0.60	0.04	8	0.64	0.03	5

Table 1.5. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
6 May	0.82	0.03	4
3 June	0.75	0.03	5
2 July	0.71	0.03	4
4 August	0.68	0.03	4
1 September	0.64	0.03	5
6 October	0.62	0.04	7
19 November	0.57	0.06	11

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

For individual pine fascicles, Figures 1 and 2 present comparisons of monthly dry matter mass loss progress during the 1990-91 study in the red pine plantation and hardwood stand types, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. The following Figures present analogous comparisons:

Figures 3 through 4 - Individual Oak Leaves
Figures 5 through 6 - Bulk Pine Fascicles
Figures 7 through 8 - Bulk Oak Leaves
Figures 9 through 10 - Bulk Maple Leaves

1985-90 Studies

Mean dry matter mass loss values for each year, litter species, and month (through 1990), along with their associated coefficients of variation (CV), are presented in Tables 1.6 through 1.10 (for the ground plantation, antenna plantation and hardwood stand, control plantation and hardwood stand, respectively). As noted above, the experimental design appropriately supports statistical data analysis by ANOVA and ANACOV. Both ANOVA and ANACOV are based on much larger samples than are the CV values reported (for each month) in Tables 1.6-1.10, and tend to explain much more variability. This is partly because n is larger, but also because factors used for statistical blocking and covariance analysis are included in the ANOVA and/or ANACOV models. The CV values presented in Tables 1.6-1.10 are therefore quite conservative when compared to ANOVA or ANACOV results.

Precision in the annual data sets is generally higher for the hardwood stand types than for the plantations. The hardwood stands represent more stable environments for making comparisons of decomposition mass loss among years than do the rapidly developing pine plantations. This is an especially important

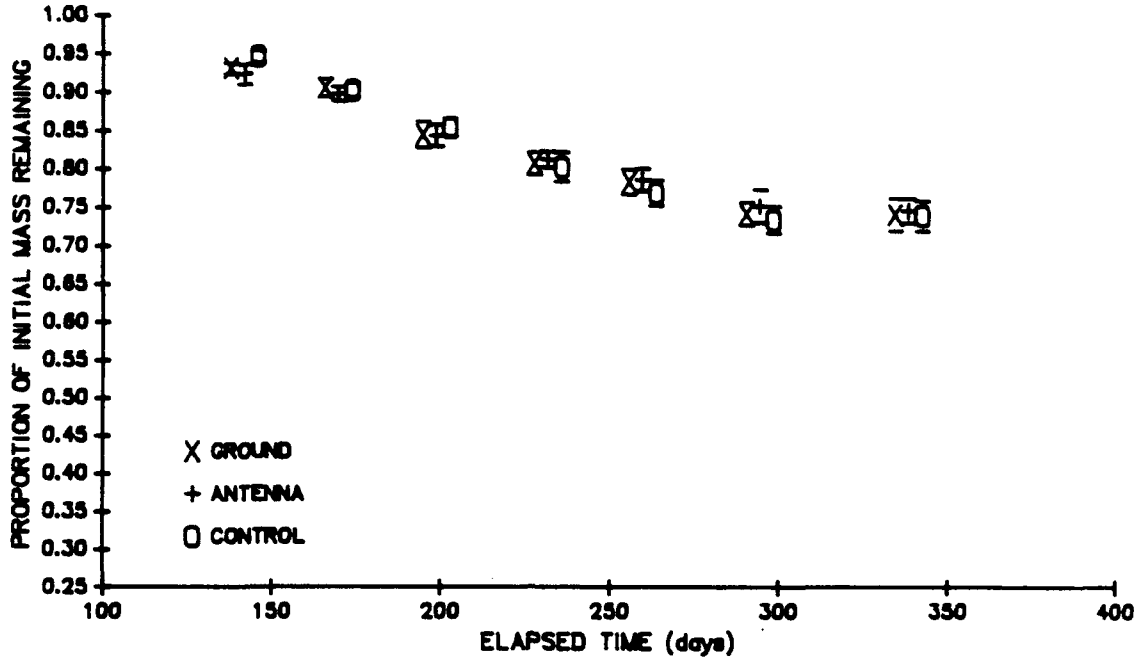

FIGURE 1. Proportion (X) of initial dry matter mass remaining for individual pine needle samples retrieved from the three plantation subunits during the 1990–1991 experiment.

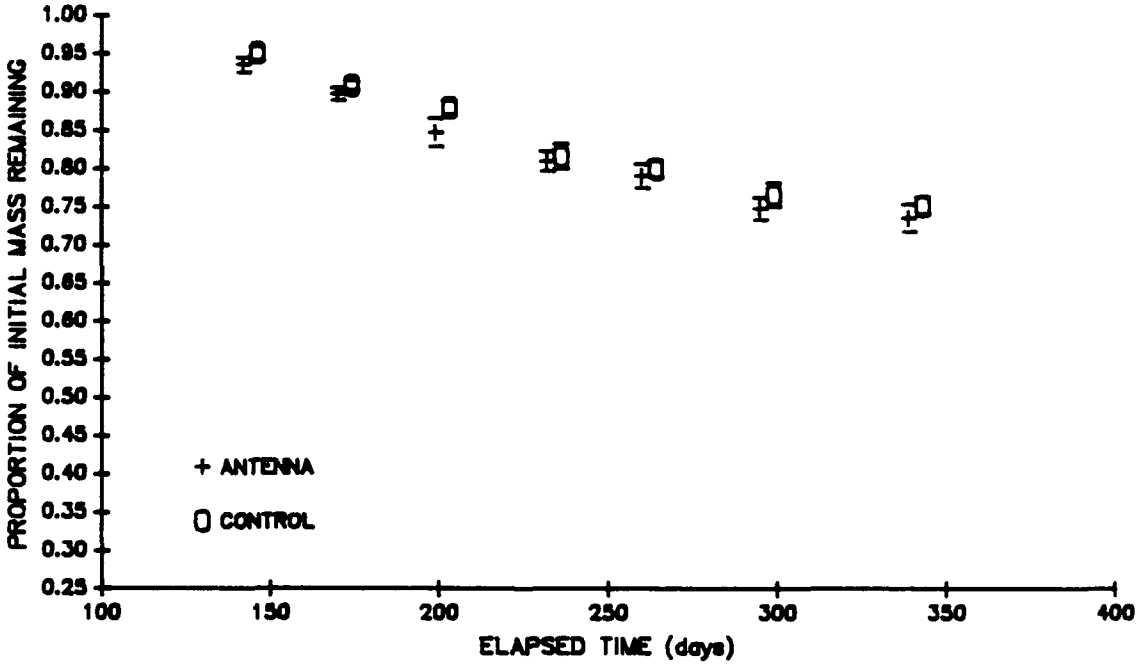

FIGURE 2. Proportion (X) of initial dry matter mass remaining for individual pine needle samples retrieved from the two hardwood stand subunits during the 1990–1991 experiment.

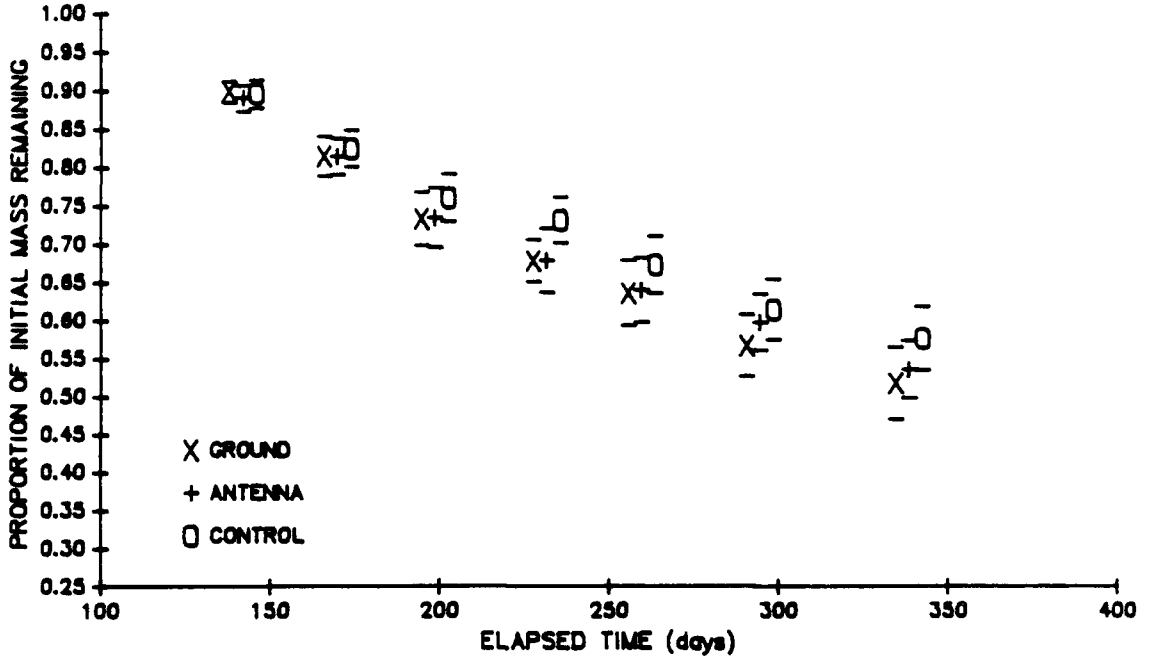

FIGURE 3. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the three plantation subunits during the 1990–1991 experiment.

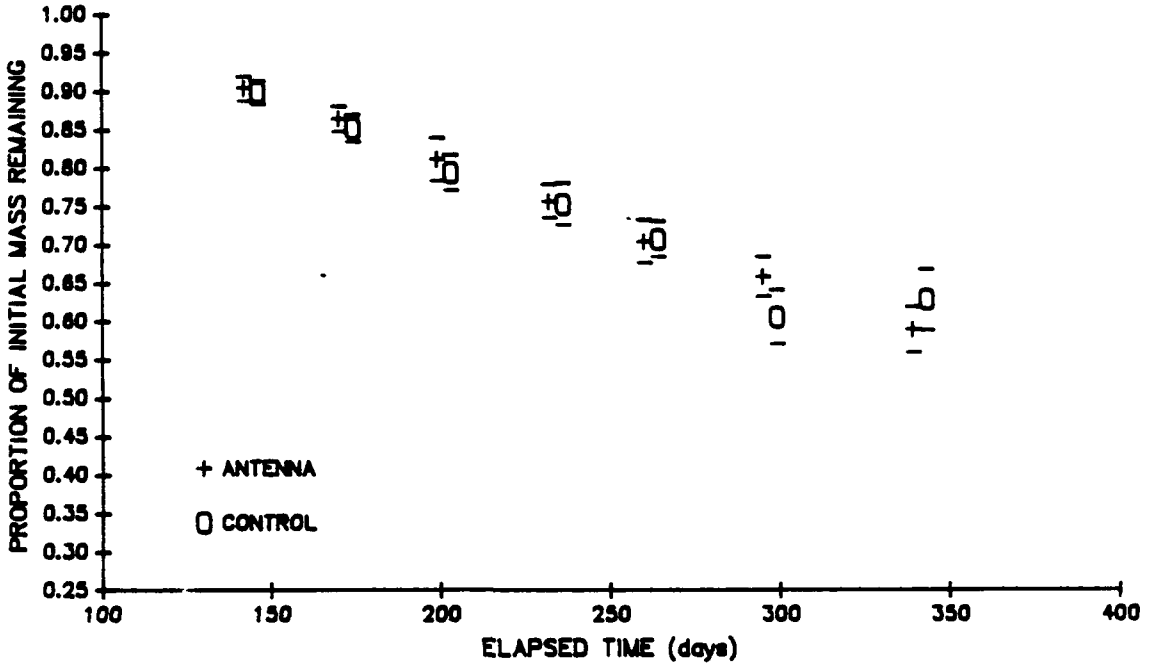

FIGURE 4. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the two hardwood stand subunits during the 1990–1991 experiment.

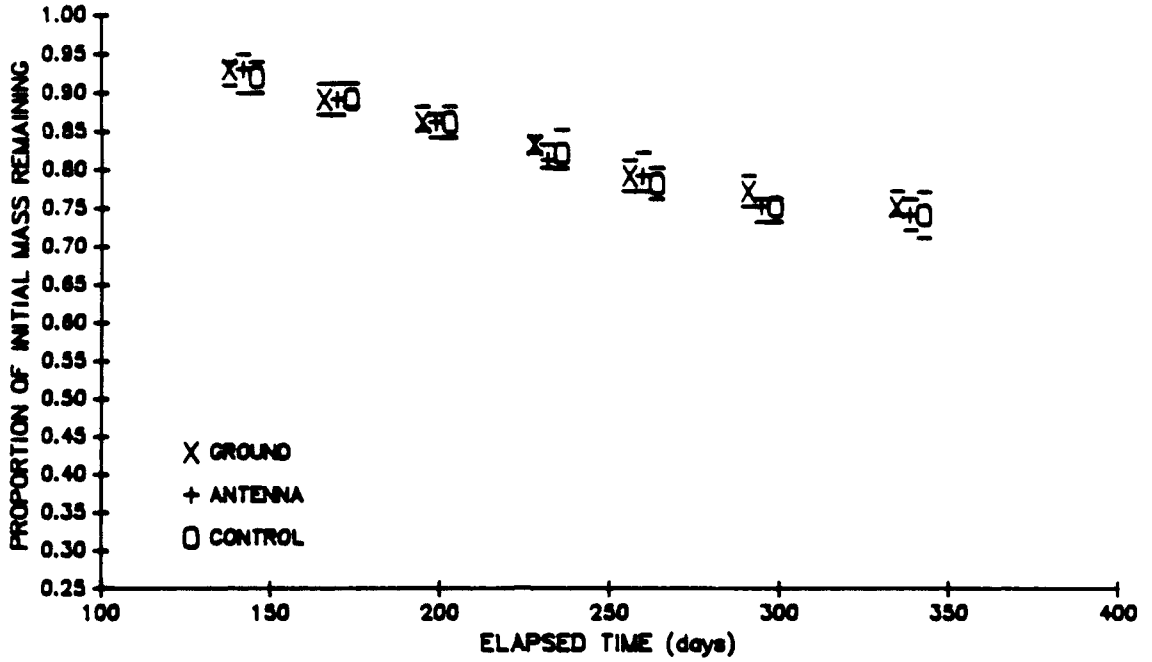

FIGURE 5. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the three plantation subunits during the 1990–1991 experiment.

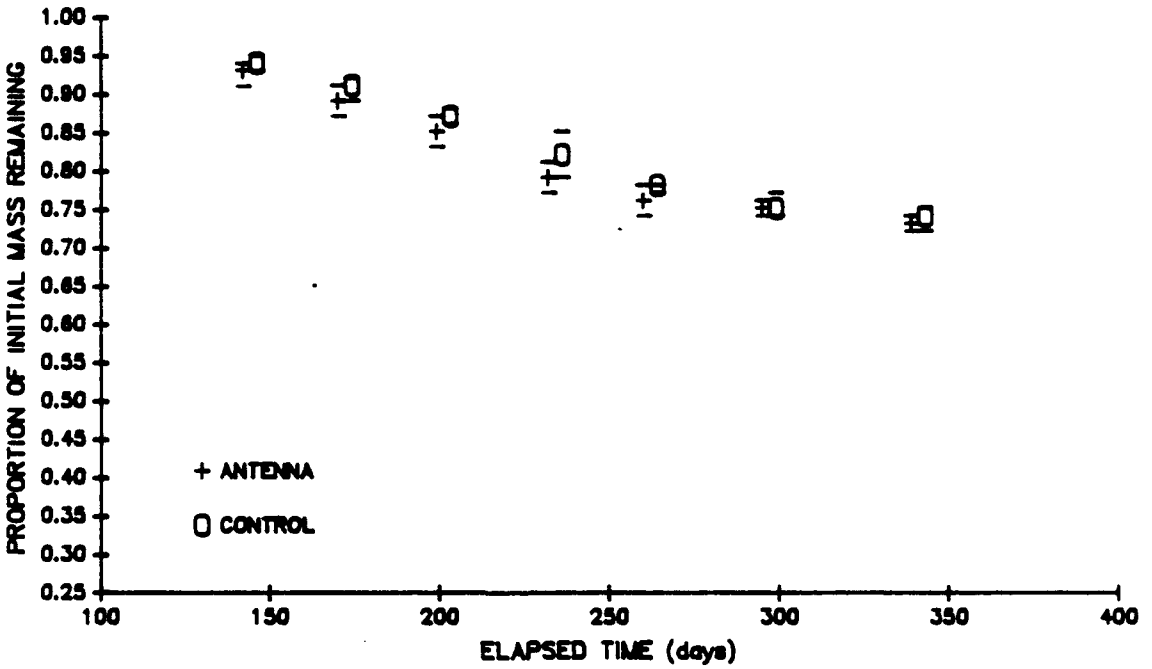

FIGURE 6. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the two hardwood stand subunits during the 1990–1991 experiment.

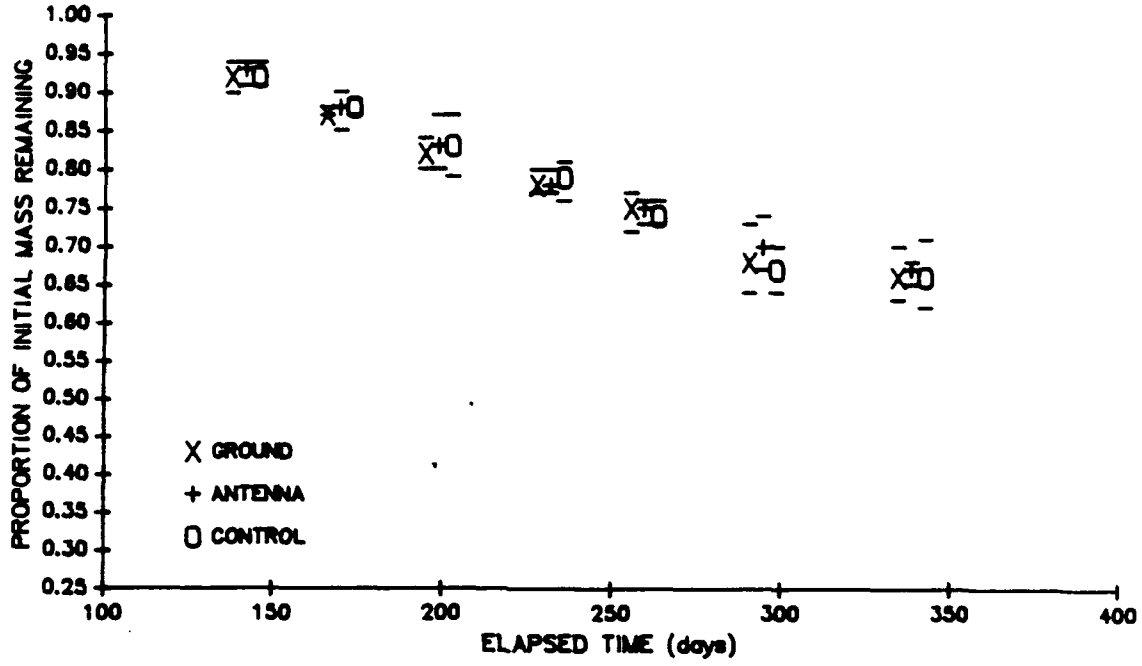

FIGURE 7. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the three plantation subunits during the 1990–1991 experiment.

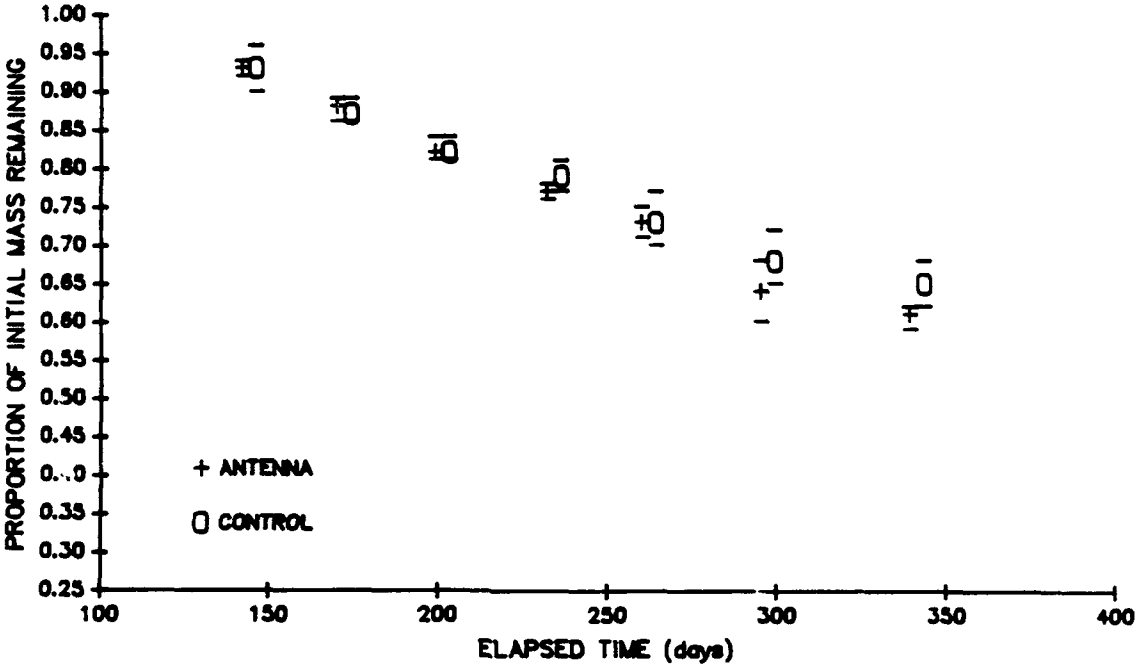

FIGURE 8. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1990–1991 experiment.

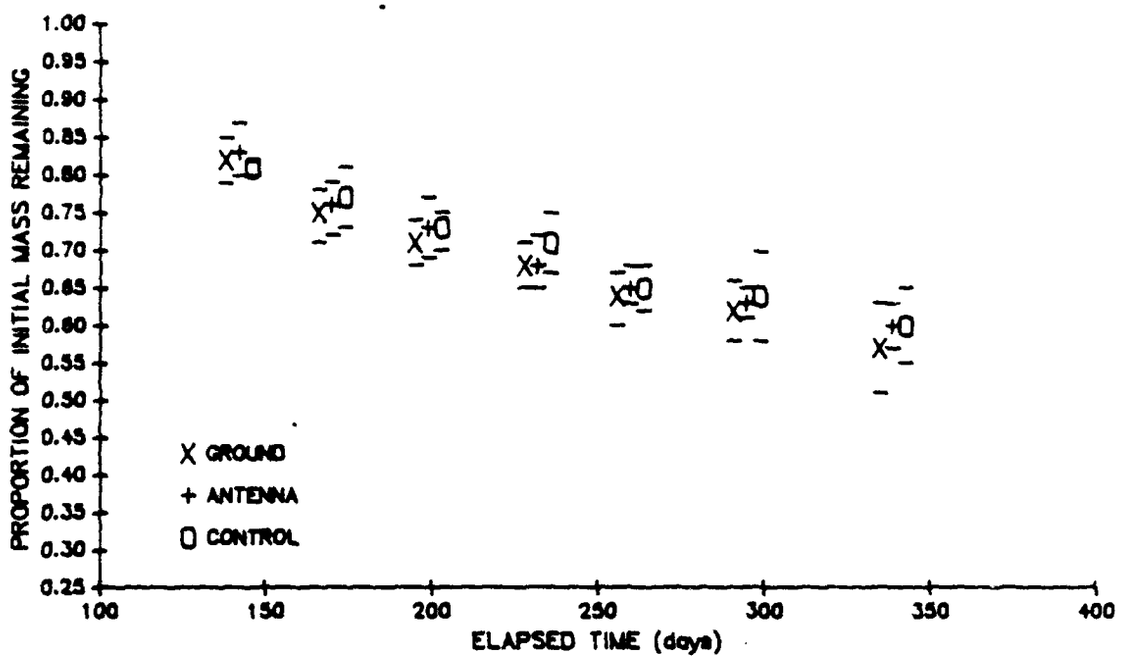

FIGURE 9. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the three plantation subunits during the 1990–1991 experiment.

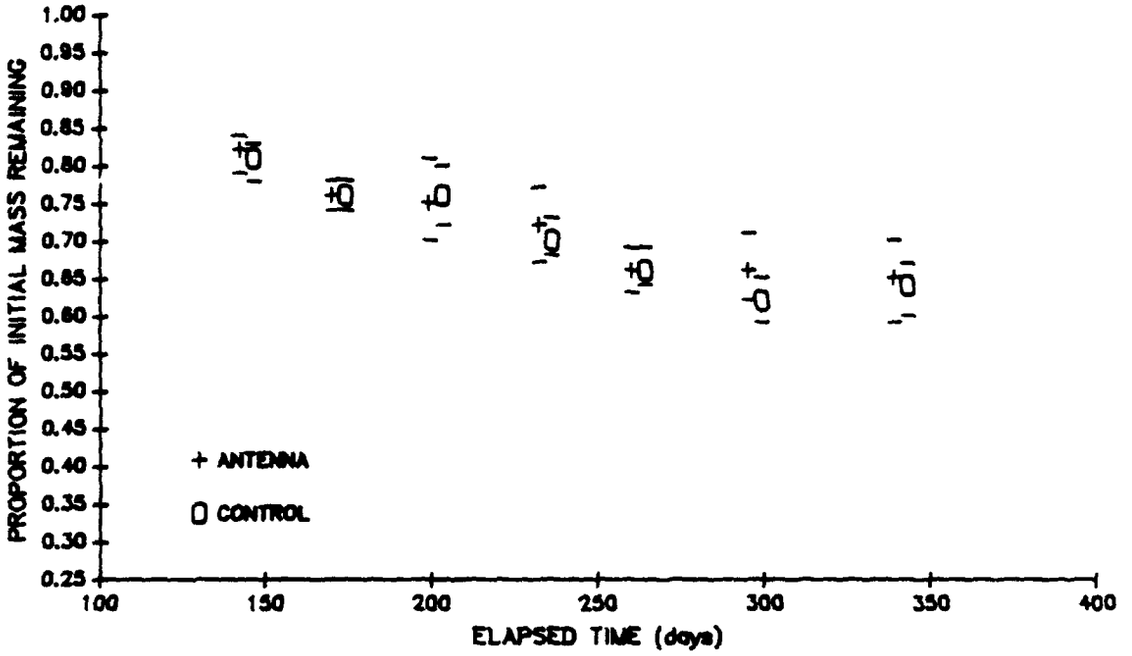

FIGURE 10. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1990–1991 experiment.

Table 1.6. Monthly mean Xw[a] and corresponding percent CV[b] for bulk litter envelopes retrieved from the **Ground Plantation.**

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.64	0.59	0.55	0.52	0.45	0.40	0.40
		CV	9.3	2.2	3.2	6.1	8.3	9.1	29.2
	Oak	Xw	0.92	0.88	0.85	0.81	0.75	0.69	0.68
		CV	2.1	1.8	1.6	2.5	4.2	4.8	6.3
	Pine	Xw	0.90	0.85	0.83	0.82	0.76	0.71	0.70
		CV	0.8	0.9	1.3	2.6	2.9	1.9	8.2
1986	Maple	Xw	0.80	0.80	0.76	0.70	0.61	0.54	0.47
		CV	3.9	3.9	2.1	5.1	7.3	10.6	23.1
	Oak	Xw	0.93	0.93	0.90	0.86	0.81	0.74	0.67
		CV	1.1	1.8	1.6	2.0	2.3	4.3	8.4
	Pine	Xw	0.91	0.87	0.88	0.84	0.81	0.72	0.71
		CV	1.8	3.6	4.8	3.8	1.4	2.6	1.5
1987	Maple	Xw	0.84	0.78	0.74	0.70	0.62	0.61	0.58
		CV	6.8	8.6	7.1	9.6	9.5	8.1	12.6
	Oak	Xw	0.92	0.94	0.87	0.80	0.79	0.76	0.74
		CV	9.8	1.3	11.9	15.5	2.6	5.0	3.3
	Pine	Xw	0.93	0.92	0.90	0.85	0.78	0.74	0.75
		CV	1.5	2.1	1.5	2.2	1.6	4.6	1.7
1988	Maple	Xw	0.77	0.70	0.68	0.63	0.56	0.51	0.50
		CV	3.0	4.0	3.5	4.0	4.6	5.2	5.4
	Oak	Xw	0.92	0.89	0.88	0.84	0.77	0.72	0.66
		CV	2.0	1.7	3.7	3.0	3.4	3.4	11.7
	Pine	Xw	0.91	0.91	0.89	0.87	0.78	0.75	0.74
		CV	1.5	3.0	0.6	1.5	2.5	1.9	5.2
1989	Maple	Xw	0.89	0.85	0.80	0.77	0.73	0.67	0.71
		CV	1.4	1.5	4.3	2.7	5.3	4.0	3.7
	Oak	Xw	0.91	0.86	0.83	0.77	0.73	0.70	0.67
		CV	4.4	3.1	2.7	4.1	4.6	4.9	6.9
	Pine	Xw	0.90	0.87	0.85	0.81	0.78	0.73	0.75
		CV	2.2	2.3	2.0	3.2	2.8	5.0	2.8
1990	Maple	Xw	0.88	0.84	0.80	0.72	0.71	0.65	0.58
		CV	2.5	4.7	5.8	4.1	8.5	5.2	4.4
	Oak	Xw	0.96	0.93	0.89	0.85	0.82	0.78	0.75
		CV	0.9	0.9	1.4	2.4	2.9	2.0	5.5
	Pine	Xw	0.94	0.92	0.87	0.86	0.83	0.79	0.75
		CV	1.1	1.8	1.6	0.6	2.4	2.4	1.3

a/ Xw is the proportion of dry matter mass remaining at sample retrieval.
b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 1.7. Monthly mean Xw[a] and corresponding percent CV[b] for bulk litter envelopes retrieved from the **Antenna Plantation.**

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.70	0.63	0.59	0.54	0.53	0.45	0.46
		CV	2.9	8.1	7.7	6.9	10.5	5.2	21.1
	Oak	Xw	0.92	0.87	0.86	0.83	0.78	0.70	0.74
		CV	3.1	3.3	2.9	2.8	3.3	6.7	10.6
	Pine	Xw	0.92	0.88	0.86	0.84	0.78	0.72	0.72
		CV	1.1	1.5	1.8	2.5	4.0	1.7	2.3
1986	Maple	Xw	0.82	0.82	0.75	0.68	0.62	0.52	0.48
		CV	3.3	2.1	3.5	2.5	7.8	5.9	6.5
	Oak	Xw	0.93	0.93	0.90	0.87	0.80	0.73	0.69
		CV	2.0	0.7	1.6	1.0	1.5	3.4	9.2
	Pine	Xw	0.92	0.90	0.89	0.86	0.81	0.76	0.74
		CV	1.4	1.8	1.8	1.4	1.9	6.7	2.9
1987	Maple	Xw	0.81	0.75	0.69	0.65	0.61	0.54	0.54
		CV	9.2	7.8	8.6	9.2	7.7	9.9	6.6
	Oak	Xw	0.94	0.86	0.88	0.81	0.76	0.74	0.71
		CV	2.8	9.0	6.5	10.6	2.5	5.3	3.5
	Pine	Xw	0.94	0.94	0.91	0.86	0.80	0.77	0.75
		CV	1.4	2.3	2.8	2.6	2.6	1.5	2.3
1988	Maple	Xw	0.76	0.70	0.68	0.63	0.56	0.51	0.50
		CV	2.8	4.0	3.8	3.7	9.7	5.5	5.6
	Oak	Xw	0.91	0.90	0.87	0.84	0.76	0.74	0.67
		CV	1.6	1.4	1.6	2.8	4.9	4.3	5.6
	Pine	Xw	0.90	0.89	0.88	0.86	0.81	0.79	0.73
		CV	2.0	1.3	1.3	2.1	2.1	3.3	2.5
1989	Maple	Xw	0.92	0.85	0.83	0.77	0.76	0.70	0.68
		CV	3.3	2.8	2.2	2.8	5.3	5.2	11.0
	Oak	Xw	0.92	0.89	0.85	0.80	0.73	0.72	0.69
		CV	4.1	2.7	2.1	8.4	6.2	6.7	7.2
	Pine	Xw	0.91	0.89	0.86	0.84	0.78	0.76	0.76
		CV	1.5	2.5	3.0	2.2	3.0	2.2	3.2
1990	Maple	Xw	0.93	0.83	0.78	0.74	0.70	0.67	0.61
		CV	3.4	5.5	3.4	3.7	5.5	6.1	11.1
	Oak	Xw	0.97	0.94	0.91	0.89	0.85	0.78	0.74
		CV	1.4	1.2	1.3	1.7	2.1	6.2	1.8
	Pine	Xw	0.95	0.93	0.90	0.88	0.84	0.79	0.74
		CV	1.3	2.6	2.5	2.4	3.3	3.7	3.6

a/ Xw is the proportion of dry matter mass remaining at sample retrieval.
b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 1.8. Monthly mean Xw[a] and corresponding percent CV[b] for bulk litter envelopes retrieved from the **Antenna Hardwood Stand.**

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.71	0.63	0.69	0.64	0.60	0.55	0.54
		CV	3.4	4.8	6.2	2.6	1.2	4.9	6.6
	Oak	Xw	0.92	0.88	0.89	0.88	0.81	0.73	0.78
		CV	1.7	0.9	2.2	3.5	3.2	5.7	12.1
	Pine	Xw	0.89	0.83	0.84	0.84	0.77	0.71	0.71
		CV	0.6	0.7	2.4	5.8	1.6	1.3	3.5
1986	Maple	Xw	0.86	0.85	0.84	0.78	0.76	0.71	0.63
		CV	1.1	2.1	3.8	3.4	4.4	6.2	4.6
	Oak	Xw	0.94	0.95	0.94	0.91	0.87	0.81	0.74
		CV	2.3	0.7	1.1	1.7	2.2	2.6	5.2
	Pine	Xw	0.94	0.91	0.91	0.86	0.79	0.75	0.72
		CV	0.9	1.9	0.9	1.0	2.0	2.4	1.7
1987	Maple	Xw	0.85	0.84	0.83	0.77	0.72	0.66	0.67
		CV	5.3	6.0	5.0	6.7	6.8	7.7	8.1
	Oak	Xw	0.96	0.97	0.92	0.87	0.80	0.75	0.75
		CV	1.3	3.3	2.0	2.0	2.6	3.4	2.5
	Pine	Xw	0.94	0.93	0.89	0.82	0.77	0.74	0.73
		CV	1.3	1.3	1.9	1.2	1.1	1.2	1.5
1988	Maple	Xw	0.75	0.73	0.72	0.67	0.64	0.55	0.56
		CV	2.5	3.3	1.6	5.1	4.7	6.0	4.4
	Oak	Xw	0.93	0.93	0.91	0.90	0.78	0.74	0.68
		CV	1.7	0.8	2.6	2.6	3.3	2.5	5.5
	Pine	Xw	0.92	0.91	0.89	0.88	0.77	0.74	0.73
		CV	0.6	0.6	1.0	1.2	0.8	1.5	1.7
1989	Maple	Xw	0.92	0.87	0.87	0.82	0.77	0.73	0.77
		CV	2.0	1.1	3.3	2.2	5.5	3.3	2.7
	Oak	Xw	0.93	0.89	0.84	0.79	0.73	0.71	0.68
		CV	1.1	3.5	3.3	3.3	2.4	6.3	4.2
	Pine	Xw	0.90	0.89	0.86	0.83	0.78	0.74	0.74
		CV	1.0	2.2	1.7	1.4	0.5	1.2	2.3
1990	Maple	Xw	0.93	0.85	0.82	0.75	0.71	0.63	0.67
		CV	4.2	3.5	2.7	4.0	8.7	5.9	12.6
	Oak	Xw	0.97	0.95	0.91	0.88	0.82	0.75	0.75
		CV	0.9	0.7	1.7	1.9	2.3	1.8	8.6
	Pine	Xw	0.94	0.93	0.88	0.83	0.81	0.74	0.73
		CV	0.8	1.6	2.2	2.3	2.7	1.4	1.8

a/ Xw is the proportion of dry matter mass remaining at sample retrieval.
b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 1.9. Monthly mean Xw[a] and corresponding percent CV[b] for bulk litter envelopes retrieved from the Control Plantation.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.70	0.62	0.57	0.56	0.50	0.53	0.48
		CV	3.7	7.7	6.4	5.4	6.8	15.6	15.0
	Oak	Xw	0.95	0.90	0.85	0.84	0.79	0.75	0.69
		CV	1.5	2.3	2.9	2.1	3.8	10.2	16.8
	Pine	Xw	0.89	0.86	0.83	0.80	0.80	0.73	0.71
		CV	1.6	1.3	1.2	0.7	6.2	4.5	2.9
1986	Maple	Xw	0.82	0.81	0.76	0.69	0.68	0.59	0.57
		CV	2.3	3.1	2.8	3.0	7.2	21.3	11.4
	Oak	Xw	0.94	0.92	0.90	0.87	0.83	0.76	0.68
		CV	1.0	1.1	1.3	2.1	2.9	5.2	11.5
	Pine	Xw	0.90	0.87	0.87	0.84	0.78	0.76	0.70
		CV	1.4	5.5	2.8	2.2	2.8	4.1	4.5
1987	Maple	Xw	0.85	0.79	0.77	0.72	0.65	0.62	0.60
		CV	1.4	2.4	2.2	3.7	4.5	6.2	4.7
	Oak	Xw	0.95	0.92	0.90	0.85	0.78	0.74	0.73
		CV	2.6	1.7	3.4	1.5	3.6	7.9	4.9
	Pine	Xw	0.92	0.91	0.88	0.84	0.77	0.74	0.74
		CV	1.9	1.3	2.6	0.6	1.2	1.5	1.9
1988	Maple	Xw	0.77	0.72	0.68	0.64	0.57	0.54	0.49
		CV	3.7	3.6	3.1	5.4	7.5	3.6	9.9
	Oak	Xw	0.95	0.90	0.89	0.87	0.79	0.75	0.68
		CV	1.0	2.2	3.6	1.8	2.6	3.4	6.1
	Pine	Xw	0.92	0.89	0.88	0.88	0.79	0.76	0.73
		CV	0.5	2.7	1.0	2.3	1.4	1.7	1.3
1989	Maple	Xw	0.91	0.86	0.83	0.81	0.73	0.72	0.72
		CV	2.8	3.5	1.9	3.0	5.5	4.0	4.7
	Oak	Xw	0.92	0.88	0.84	0.81	0.75	0.70	0.68
		CV	1.7	1.3	2.7	2.5	2.9	2.5	5.5
	Pine	Xw	0.91	0.88	0.85	0.81	0.79	0.73	0.76
		CV	2.2	1.8	1.3	3.1	1.7	1.7	5.6
1990	Maple	Xw	0.93	0.82	0.77	0.72	0.69	0.63	0.62
		CV	3.3	2.4	3.3	6.5	6.1	4.5	11.8
	Oak	Xw	0.97	0.94	0.90	0.87	0.82	0.76	0.72
		CV	1.0	1.6	1.9	2.4	1.9	3.0	2.5
	Pine	Xw	0.93	0.93	0.90	0.87	0.83	0.78	0.74
		CV	2.6	1.4	2.0	3.3	2.4	3.9	3.9

a/ Xw is the proportion of dry matter mass remaining at sample retrieval.
b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 1.10. Monthly mean Xw[a] and corresponding percent CV[b] for bulk litter envelopes retrieved from the Control Hardwood Stand.

Year	Species		Month						
			May	Jun	Jul	Aug	Sep	Oct	Nov
1985	Maple	Xw	0.72	0.65	0.64	0.64	0.58	0.54	0.51
		CV	3.0	2.5	2.4	3.2	3.7	5.5	4.7
	Oak	Xw	0.93	0.90	0.87	0.87	0.79	0.70	0.68
		CV	1.1	1.6	1.0	5.4	2.5	4.5	4.1
	Pine	Xw	0.89	0.83	0.83	0.81	0.77	0.71	0.70
		CV	0.9	0.6	1.1	2.4	1.8	1.9	3.4
1986	Maple	Xw	0.84	0.85	0.82	0.77	0.75	0.69	0.63
		CV	2.7	1.1	3.1	3.8	2.2	4.4	4.0
	Oak	Xw	0.94	0.95	0.93	0.91	0.85	0.78	0.72
		CV	0.6	1.1	1.0	1.5	2.4	0.7	1.6
	Pine	Xw	0.93	0.92	0.89	0.85	0.79	0.75	0.72
		CV	0.9	2.0	2.2	1.3	1.8	1.2	1.8
1987	Maple	Xw	0.87	0.83	0.84	0.81	0.75	0.71	0.70
		CV	1.7	2.3	2.4	3.5	5.7	4.8	5.0
	Oak	Xw	0.95	0.93	0.90	0.86	0.80	0.71	0.74
		CV	1.4	1.8	1.9	1.7	3.5	10.0	3.1
	Pine	Xw	0.94	0.92	0.88	0.83	0.77	0.74	0.73
		CV	1.3	1.4	1.2	1.0	2.0	2.4	2.3
1988	Maple	Xw	0.80	0.76	0.75	0.71	0.66	0.64	0.62
		CV	2.4	3.2	4.6	4.0	5.7	4.7	8.4
	Oak	Xw	0.95	0.94	0.94	0.92	0.84	0.77	0.73
		CV	1.1	1.1	1.8	1.8	2.7	4.0	4.1
	Pine	Xw	0.94	0.92	0.92	0.92	0.82	0.78	0.75
		CV	0.8	0.7	1.1	0.8	1.5	1.5	2.8
1989	Maple	Xw	0.92	0.90	0.88	0.87	0.81	0.80	0.80
		CV	3.3	2.7	2.1	2.8	1.9	3.6	3.1
	Oak	Xw	0.92	0.90	0.86	0.82	0.78	0.75	0.73
		CV	1.8	3.0	3.6	3.5	4.2	3.8	4.9
	Pine	Xw	0.92	0.89	0.87	0.83	0.81	0.78	0.77
		CV	2.2	2.6	2.7	2.4	1.6	2.0	1.1
1990	Maple	Xw	0.93	0.87	0.84	0.80	0.76	0.67	0.69
		CV	3.7	5.8	3.7	4.4	5.8	6.4	5.6
	Oak	Xw	0.97	0.96	0.93	0.89	0.83	0.76	0.74
		CV	0.5	0.8	2.2	1.8	1.2	1.2	4.3
	Pine	Xw	0.96	0.96	0.92	0.88	0.84	0.76	0.74
		CV	0.9	0.8	1.8	2.8	5.8	1.4	3.5

a/ Xw is the proportion of dry matter mass remaining at sample retrieval.
b/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

consideration with respect to our objective of detecting possible effects of increasing ELF electromagnetic field exposures.

Among the study species, pine and oak have provided the most precise data. On average, bulk samples of each species lose approximately 25 to 30 percent of initial dry matter mass during their first year on the forest floor. Maple data are the least precise, with samples losing 29 to 60 percent of initial mass.

ANOVA indicated that bulk litter samples of all three species decomposed faster in the antenna site hardwood stand than in the control site hardwood stand, from 1988 through 1990. Prior to 1988, ANOVA detected no significant difference in mass loss progress between the two stands, except that oak litter decomposed faster in the control hardwood stand during 1987. ELF EM field exposures have increased steadily at the antenna site since 1987. The year-by-site interactions in the plantation data set are less straightforward, but the plantations are also much less homogeneous and less stable ecosystems for study than are the hardwood stands.

Explanation of all differences in decomposition rate among years for all litter sample types may be an unrealistic goal, especially for the plantations, where vegetational changes are proceeding at different rates and interacting with yearly weather differences. Effects model ANOVAs ranked years differently for each litter species. This is not surprising, in that the annual parent litter collections probably differ substantially in substrate quality, even though parent collections are made at the same locations each year. To the extent that substrate quality affects decomposition rate, and that years rank differently in quality for each litter species, it should be expected that years would rank differently in rate of dry matter mass loss for the three species.

Detection limits, derived from ANACOV models containing only sets

of seasonal temperature- and precipitation-related variables and sample retrieval date correction covariates, are presented in Table 1.6. Detection limits for mean X_w, among years and sites, are comparable for both the hardwood stands and the plantations. Litter species ranked maple > oak > pine, in order of decreasing detection limits. Detection limits were all below 5 percent, except for the 1985 maple litter (in both the hardwood stands and the plantations), where limits were still below 7 percent. All detection limits for site changes were below 2 percent. These low detection limits represent another major challenge to our ability to effectively explain, with ANACOV, the differences detected by ANOVA.

A summary of recent statistical analyses and corresponding preliminary results is presented as Table 1.11. All covariate names are defined in Table 1.12. In Table 1.11, the results of two different ANACOV efforts are presented for each species and stand type, except for maple litter in the plantations. First, the simplest model found to explain the year-by-site interaction and/or the differences detected among years and sites by ANOVA is presented. These models are taken from the 1990 Annual Report, and include 60 Hz and/or 76 Hz field exposure-related variables as covariates, where useful. This first ANACOV effort did not, however, include either the recently developed sets of seasonal weather-related covariates or the sample retrieval date correction terms. The second set of models includes only the sample retrieval date correction terms and sets of seasonal weather-related variables as covariates. Because of limitations on the availability of data for some of the covariates, the first set of ANACOV models is restricted to 1985-1988, whereas the second set includes 1985-1990.

The indication of possible ELF field effects on maple and oak litter decomposition in the hardwood stands, and on oak and pine litter decomposition in the plantations, is based on the effect of including 76 Hz field exposure-related variables as covariates

Table 1.11. Summary of statistical analyses and results for measured variables, Element 1.

Variable	Model	Test Procedure[a]	Covariates[b]	Treatments	Findings Through 1990[c]
X_w (proportion of initial dry matter mass remaining)					
	Maple, Hardwood Stands				
		ANACOV	AET, PCN, PCP, STDPCLIG, L60, L76, M76, T76	Year, Site	Possible ELF Effect
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR01s	Year, Site Siteyear	No Detectable Effect
	Oak, Hardwood Stands				
		ANACOV	AET, PCN, STDPCLIG, L60, L76, M76, T76	Year, Site	Possible ELF Effect
		ANACOV	DEV*MONTH, ATDDs, PRCs, PR10s	Year, Site Siteyear	No Detectable Effect
	Pine, Hardwood Stands				
		ANACOV	ST5DDRT, PRWRT, PR.01RT, STDPCLIG, PCN, PCP, L60	Year, Site	No Detectable Effect
		ANACOV	DEV*MONTH, ST5DDs, PRCs, PR01s	Year, Site Siteyear	No Detectable Effect

Table 1.11. Summary of statistical analyses and results for measured variables, Element 1 (continued).

Variable	Model	Test Procedure[a]	Covariates[b]	Treatments	Findings Through 1990[c]
X_w (proportion of initial dry matter mass remaining)					
	Maple, Plantations				
		ANACOV	DEV*MONTH, ATDDs, PRCs, PR01s	Year, Site Siteyear	No Detectable Effect
	Oak, Plantations				
		ANACOV	AET, PCN, L60, L76, M76, T76	Year, Site	Possible ELF Effect
		ANACOV	DEV*MONTH, ATDDs, PRCs, PR10s	Year, Site Siteyear	No Detectable Effect
	Pine, Plantations				
		ANACOV	ST5DDRT, PRWRT, PR10RT, STDPCLIG, PCN, PCP, L60, L76, M76, T76	Year, Site	Possible ELF Effect
		ANACOV	DEV*MONTH ATDDs, PRCs, PR01s	Year, Site Siteyear	No Detectable Effect

a/ ANACOV = Analysis of Covariance (PROC GLM, SAS)
b/ Covariate names are defined in Table 1.12. The suffix "s" in a covariate name specifies the set of 3 seasonal covariates (e.g., ATDDs = ATDDSPR, ATDDSUM, and ATDDFAL).
c/ All statistical tests are at p = 0.05.

Table 1.12. Definitions for names of variables used in ANACOV models presented in this proposal.

ATDDRT	-the running total of air temperature degree days (30 cm above ground, 4.4°C basis); available 1985-1990.
ATDDs	-the set of seasonal covariates ATDDSPR (air temperature degree days, April through early July), ATDDSUM (early July through early September), and ATDDFAL (early September through early November); available 1985-1990.
ST5DDRT	-the running total of soil temperature degree days (5 cm below ground, 4.4°C basis); available 1985-1990.
ST5DDs	-the set of seasonal covariates ST5DDSPR, ST5DDSUM, and ST5DDFAL (see ATDDs); available 1985-1990.
PR01RT	-the running total of days with rainfall totaling 0.01 inch or more; available 1985-1990.
PR01s	-the set of seasonal covariates PR01SPR, PR01SUM, PR01FAL (see ATDDs); available 1985-1990.
PR10RT	-the running total of days with rainfall totaling 0.1 inch or more; available 1985-1990.
PR10s	-the set of seasonal covariates PR10SPR, PR10SUM, and PR10FAL (see ATDDs); available 1985-1990.
PRWRT	-the running total of precipitation; available 1985-1990.
PRCs	-the set of seasonal total precipitation covariates PRCSPR, PRCSUM, and PRCFAL (see ATDDs); available 1985-1990.
AET	-actual evapotranspiration (Thornthwaite and Mather 1957, Meentemeyer 1978); available 1985-1989.
STDPCLIG	-initial percent lignin content of each annual parent litter collection; available 1985-1989.
PCN	-percent nitrogen content of retrieved litter samples; available 1985-1986, 1987-1988 (May, July, September, October).
PCP	-percent phosphorus content of retrieved litter samples; available 1985-1986, 1987-1988 (May, July, September, October).
L60	-longitudinal 60 Hz field strength (mV/m); available 1985-1988.
L76	-longitudinal 76 Hz field strength (mV/m); available 1985-1989.
M76	-magnetic flux 76 Hz exposure levels (mG); available 1985-1989.
T76	-transverse 76 Hz field strength (V/m); available 1985-1989.
DELAY	-elapsed time in days between excavation of red pine seedlings and delivery of mycorrhizae to the lab for streptomycete studies; available 1986-1990.
PH	-mean pH of rhizosphere soil associated with red pine mycorrhizae sampled for streptomycete studies; available 1986-1990.

in ANACOV. In the first ANACOV effort reported, year, and year-by-site interaction for pine in the hardwood stands were explained only when L60 was added as a covariate (site could already be explained by other covariates). For oak in the hardwood stands, year was explained only with the inclusion of L60, and year-by-site was only explained by adding L76, M76, and T76 (no difference between sites was detected by ANOVA). For maple in the hardwood stands, year and year-by-site were only explained by including L60, L76, M76, and T76 (no difference between sites was detected by ANOVA). For pine and oak in the plantations, inclusion of L60, L76, M76, and T76 provided explanation of site, but not year (year-by-site was already explained by other covariates). For maple in the plantations, no difference among sites was detected by ANOVA, but no combination of covariates explained year, site, or year-by-site interaction.

Analysis in the second ANACOV effort placed more emphasis on evaluating the trends among years, sites, and siteyears, with respect to ELF operations, rather than on complete explanation of year, site, and year-by-site interaction. Nevertheless, no difference was detected between the two hardwood stands for maple, oak, or pine, or among the three plantations for maple. Also, the patterns of differences detected for oak and pine among the three plantations did not present a gradient suggestive of an ELF field effect. Years were not completely explained for any of the three species, in either the hardwood stands or the plantations.

Nevertheless, none of the patterns of differences among years presented a gradient suggestive of an ELF field effect. Finally, though the year-by-site interaction was significant for all three species, both in the hardwood stands and in the plantations, none of the patterns of siteyear differences (from the means ANOVA models) presented a gradient suggestive of an ELF field effect.

Summary of Results

Covariates based on ELF EM field data for 1985-1988 helped explain differences in mass loss progress among sites (both hardwood stands and plantations) and among years (hardwood stands only), and the year-by-site interactions for both hardwood stands and plantations. We suspect, however, that the contributions of ELF EM field data to our ANACOV models may be spurious, a result of having too few years of field data. Preliminary studies with recently developed seasonal weather-related covariates and a covariate based on the deviations in sampling dates among years suggest that we may (with additional field data for the 1992-1993 operational years) be able to explain differences in decomposition rates without ELF EM field exposure data.

Proposed Work

We propose to continue monitoring dry matter mass loss from leaf litter on a monthly basis, in all five study locations (i.e., the two hardwood stands and three plantations) during the 1992 and 1993 field seasons. The hardwood stands and plantations present very different environments for decomposition. Although plantation vegetation and consequently the ground level environments in the plantations have been changing rapidly, detection limits for years and especially for sites are very low, and changes in decomposition progress attributable to environmental differences among years and sites are being explained with increasing effectiveness by covariate analysis.

We propose to continue study of the same three litter species (red maple, northern red oak, and red pine) used since 1985. These three litter species differ dramatically in their structure and composition, and hence the strategy of their decomposition. Each litter species therefore favors different components of the forest floor microbial community, and has a valuable role in the testing for ELF EM field effects on the integrated functional

capacity of forest floor litter decomposer communities.

As discussed above, covariates based on ELF EM field exposure data helped explain differences in mass loss progress. This was true for all three litter species. Again, we suspect that our ANACOV efforts will be able to explain these same differences without the use of ELF EM field exposure-related covariates, through use of seasonal weather-related variables and the deviation-by-month interaction term as covariates, and with the inclusion of data for the operational years 1992 and 1993.

Bulk leaf and individual leaf samples generally decompose at very similar rates (Bruhn et al. 1992), and the detection limits associated with bulk leaf samples are adequate for detection of very subtle environmental perturbations of the litter decomposition process. Bulk samples also provide sufficient mass on retrieval for nutrient analysis. For these reasons, we propose to eliminate study of individual leaf samples, beginning with the 1991/1992 annual experiment.

Element 2: RED PINE SEEDLING RHIZOPLANE STREPTOMYCETES

Introduction

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectomycorrhizae, and can influence mycorrhizosphere microbial population composition through production and excretion of compounds such as antibiotics, vitamins, amino acids, and hormones (Marx 1982, Keast and Tonkin 1983, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk et al. 1987, Richter et al. 1989). Streptomycetes have also been found to degrade calcium oxalate, cellulose, and lignin/lignocellulose, in both coniferous and deciduous litter systems (Graustein et al. 1977, Crawford 1978, Knutson et al. 1980, Antai and Crawford 1981, McCarthy and Broda 1984). As part of the indigenous soil and root-related microflora, populations of streptomycetes are not considered to undergo great population changes in stable ecosystems (Orchard 1984). For these reasons, streptomycete populations associated with the mycorrhizae of the planted red pine seedlings were selected for inclusion in these long-term studies.

Nevertheless, we propose to terminate this work element in 1992, for several reasons. This would result in no further field data collection, and preparation of a final report during 1992. First, ANACOV has explained all differences, both in streptomycete population levels and taxonomic richness, among years (through 1990) and among the three study plantations, as well as the year-by-site interaction. There is no indication of any ELF field effect on mycorrhizoplane streptomycete populations. It must be noted, however, that the 1991 field data have not yet been included in the analysis. Second, the discontinuation of Armillaria root disease studies by the Upland Flora Studies project has caused us to propose adoption of this work element into the Litter Decomposition and Microflora project. The resulting financial squeeze is another compelling reason for discontinuing the streptomycete studies. Third, in contrast to

the streptomycete analysis, there is preliminary evidence to suggest the possibility of an ELF field effect on the rates of root disease progress in the three plantations. Fourth, occasional problems with obtaining appropriate samples, or with fungal contamination of samples, have resulted in incomplete streptomycete data sets, for which the planned sample size was already modest. In contrast, the root disease mortality data set is complete. Also, the streptomycete analysis is based on very modest sample size, whereas the root disease studies are based on 100 percent surveys of the study plantations.

Methods

These studies have involved the enumeration and characterization of streptomycetes associated with the red pine mycorrhizoplane (i.e., washed mycorrhizal fine roots). Mycorrhiza Type 3, which has predominated in all three ELF study plantations since their establishment, was selected for study. To assess the effects of ELF fields on mycorrhizoplane streptomycete populations, the objectives of this work element have been to: 1) characterize the size and taxonomic richness of these populations prior to and during operational use of the ELF antenna, and 2) use these data to test hypotheses of possible changes in these population variables due to ELF fields.

The hypotheses tested are that there are no differences among years or plantations in either 1) the overall levels of mycorrhizoplane streptomycetes, or 2) the numbers of streptomycete morphotypes recovered, that cannot be explained using factors unaffected by ELF fields. The regularity with which specific morphotypes were recovered has also been noted.

The experimental design called for monthly (May through October) analysis of six washed red pine Type 3 mycorrhizal fine root samples from each of the three study plantations (ground, antenna, and control sites). Each month, on each of the three

plots comprising each plantation, five seedlings were excavated by the Upland Flora Studies project for mycorrhiza studies. Six independent samples per plantation were derived by compositing two or three of the seedlings from each plot. Exceptions occasionally occurred, when fewer samples were provided for testing. Delivery of washed root samples for streptomycete analysis was generally delayed by 1 to 2 weeks from the time root samples were collected in the field. However, delays of 23 and 29 days occurred in September and October of 1989. This "delay" has been successfully used as a covariate to help explain differences among years and months in numbers of streptomycete morphotypes recovered. Samples were stored at 4°C and processed within 12 hours of receipt by the Environmental Microbiology lab in the Department of Biological Sciences.

Levels of Mycorrhizoplane Streptomycetes

A pre-weighed portion (0.1 g) of washed roots was placed in 9.9 ml of sterile 0.01 M phosphate buffer (pH 7.2), and homogenized for serial dilution in more sterile buffer. Two larger portions of the washed roots (about 0.5 g each) were separately weighed, and then dried (60°C) for determination of dry weights.

Three dilutions (in duplicate) of each washed root sample were spread-plated onto starch casein agar (SCA) in Petri dishes. Cycloheximide (50 mg/l) and nystatin (50 mg/l) were added to the SCA to prevent fungal growth (Andrews and Kennerly 1979, Goodfellow and Dawson 1978). All plates were incubated at 20°C, and total numbers of streptomycete colonies were determined after 14 days. Counts were expressed as estimates of streptomycete levels per gram dry weight of mycorrhizal fine root.

Numbers of Mycorrhizoplane Streptomycete Types

After enumeration, individual streptomycete colonies were characterized to determine the number of morphotypes per sample. All colonies with the same characteristics (i.e., presence/absence of diffusable pigment, presence/absence of aerial mycelium, color of aerial mycelium and any diffusable pigment, and reverse colony color) were considered to represent one morphotype or strain (Keast et al. 1984). The numbers of morphotypes observed per sample were expressed as the estimated number of morphotypes present per gram dry weight of mycorrhizal fine root.

Data for both streptomycete levels and morphotype numbers, based on the SCA plate counts, were transformed to $\log_{10}$ for statistical analysis (Orchard 1984). All statistical analyses were conducted using PROC GLM of the Statistical Analysis System (SAS 1985). Three-way ANOVA was used to compare years (1985 through 1990), sampling dates (month), and the three plantation study sites (Ground, Antenna, and Control), as well as to evaluate the possibility of a year-by-site interaction (Zar 1984). Wherever ANOVA showed significant differences ($\alpha = 0.05$) among years, sampling dates, or plantations, the Least Squares Means option (SAS, PROC GLM) was used to conduct multiple comparisons between years, sampling dates, and/or plantations.

Covariates have been used (SAS, PROC GLM) to explain differences in streptomycete levels or morphotype numbers, between years and/or plantations, as detected by ANOVA. Most of the covariates tested, with the exceptions of rhizosphere pH and sample processing "delay", are weather-related variables, due both to their effectiveness and to their presumed independence of ELF field influence. Wherever ANACOV detected significant differences, the results of pairwise comparisons (Least Squares Means option) have been presented.

Morphotype Distribution and Characterization

The representation of recognizable morphotypes found in each year's samples was compared to observations from similar samples from other years. This allows us to determine if some of the same types are still present on the red pine seedlings after six years or more in the field, and to determine whether the same types are present in all three ELF study plantations.

Throughout the study, colonies of each morphotype have been periodically retained in culture for further study. To evaluate the morphotypes' potential contribution to mycorrhiza/root development, and to confirm previous results with each morphotype, isolates of each morphotype have been tested to evaluate their abilities to degrade calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose (Smith 1977), and lignocellulose (Sutherland 1985).

Description of Progress

1990-91 Study

Data for 1991 streptomycete levels and morphotype numbers associated with washed type 3 mycorrhizal fine roots are presented in Tables 2.1 and 2.2, as the mean and the standard error of the sample mean, for up to six samples per plantation. The 1991 seasonal patterns for levels and morphotype numbers in the three plantations are presented in Figures 2.1 and 2.2, as $\log_{10}$-transformed data. The relatively large S.E. values for both levels and types result partially from often having data from less than six samples per plantation and date. This has resulted historically when less than six samples per site were provided on occasion, or when insufficient sample mass was provided for replicate analyses, or due to bacterial/fungal contamination of samples.

Table 2.1. Levels of streptomycetes (x 10^5) isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1991.

Sampling Date	Sampling Site								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	N[c]	Mean	S.E.	N	Mean	S.E.	N
21 May 1991	1.2	0.14	6	1.3	0.25	6	1.4	0.30	5
18 June 1991	3.5	0.58	6	2.1	0.44	6	3.3	0.69	3
16 July 1991	2.8	0.51	6	3.2	0.74	5	5.1	0.82	4
13 Aug. 1991	1.8	0.51	4	1.8	0.34	6	1.0	0.39	4
9 Sept. 1991	0.7	0.01	3	4.3	0.29	3	0.1		1
14 Oct. 1991	0.6	0.18	2	0.6		1	0.5	0.18	3

a/ mean value (per gram of soil, o.d.w.)

b/ standard error of the mean

c/ up to six samples per plot, each sample representing the composited roots of 2-3 red pine seedlings

Table 2.2. Levels of streptomycete morphotypes isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1991.

Sampling Date	Sampling Site								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	N[c]	Mean	S.E.	N	Mean	S.E.	N
21 May 1991	2.7	0.33	6	3.7	0.33	6	3.0	0.63	5
18 June 1991	3.3	0.49	6	3.3	0.49	6	2.3	0.34	3
16 July 1991	2.5	0.34	6	2.6	0.25	5	3.2	0.47	4
13 Aug. 1991	2.3	0.26	4	2.2	0.17	6	2.3	0.26	4
9 Sept. 1991	2.3	0.34	3	3.7	0.89	3	2.0		1
14 Oct. 1991	2.0	0.00	2	2.0		1	2.0	0.00	3

a/ mean value (per gram of soil, o.d.w.)

b/ standard error of the mean

c/ up to six samples per plot, each sample representing the composited roots of 2-3 red pine seedlings

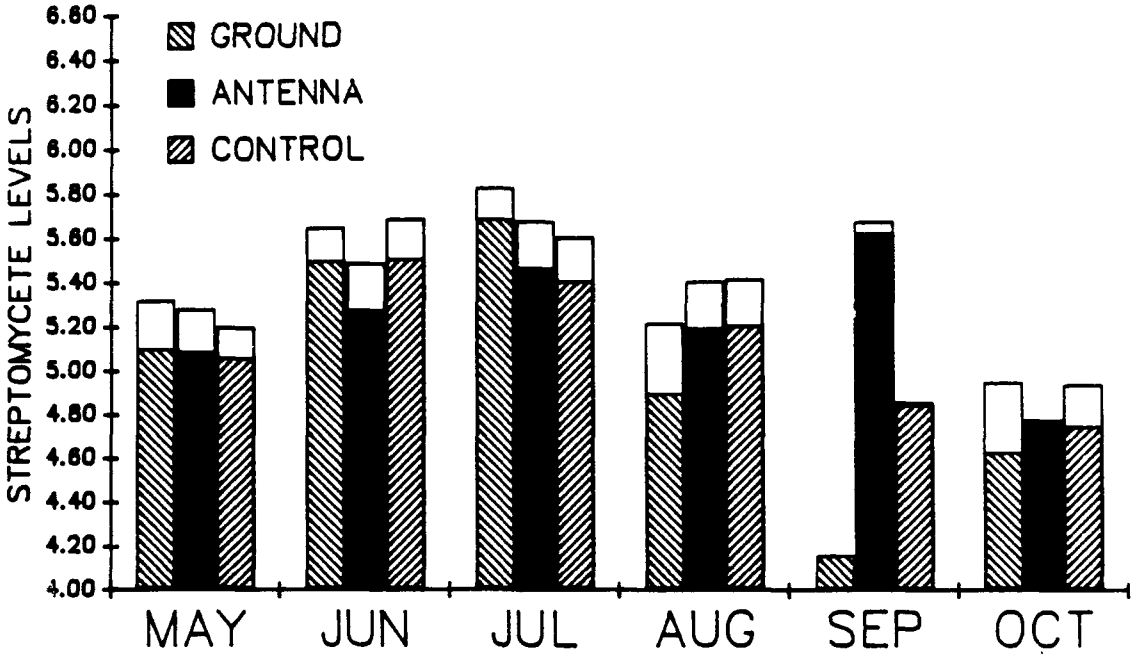

FIGURE 2.1. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycetes in the three study plantations during 1991.

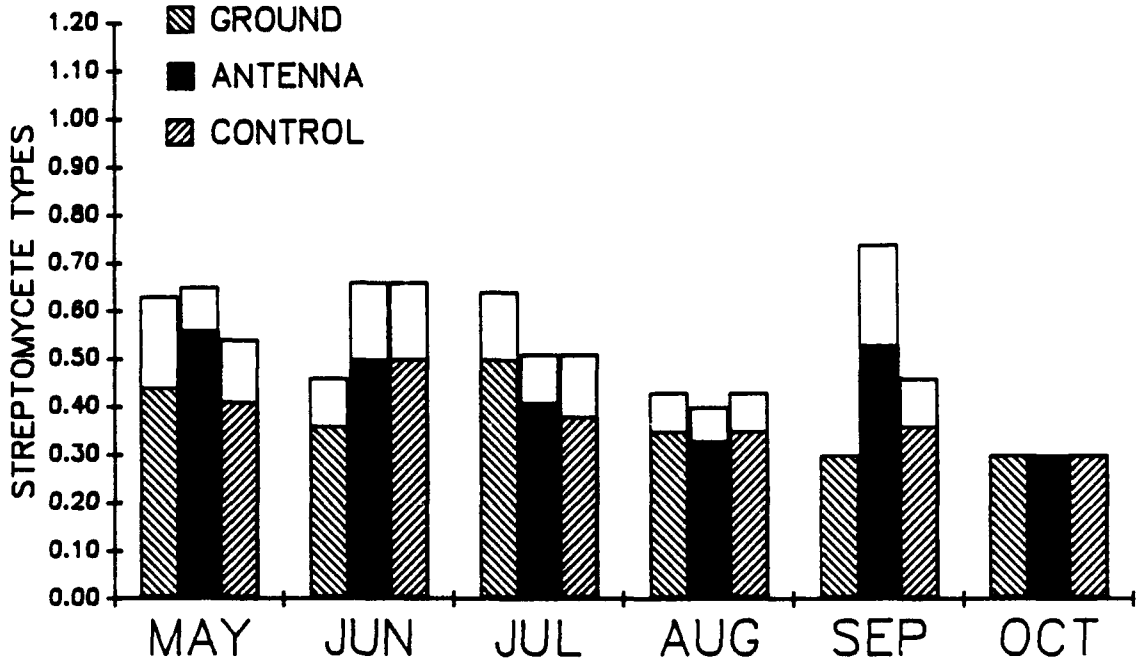

FIGURE 2.2. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycete morphotypes in the three study plantations during 1991.

1985-90 Studies

Correlation analyses were conducted as the first step in exploring relationships of seasonal patterns of streptomycete levels and morphotype numbers with weather, other environmental, and vegetation-associated variables. Over 30 variables related to temperature, precipitation, soil moisture, actual evapotranspiration (AET), nutrient status, rhizosphere soil pH, previous forest cover, mycorrhizae levels, seedling growth and vigor, and delay in sample delivery to the lab were evaluated. Some of the variables having p values less than 0.05 and correlation coefficients greater than |0.3000| were selected as potential covariates in the initial ANACOV studies. Priority has been given to rhizosphere soil pH, weather-related variables, and "delay", which appear at least to be independent of direct ELF field influence. Temperature- and precipitation-related variables were evaluated in two basic forms: 1) as the running totals leading up to each sampling date, and 2) as totals for the 30 day period previous to each sampling date. AET was calculated based on soil moisture retentions of 300 mm for all three plantations (Thornthwaite and Mather 1957, Meentemeyer 1978). We are relying on the Upland Flora Studies project to test the ELF-independence of our weather-related covariates. So far, soil temperature (5 cm) and precipitation-related covariates appear to behave in an ELF-independent manner ("Trees" Annual Report 1990, Element 1. Ambient Monitoring, pages 9-59). Air temperature (2 m), however, has been consistently higher in the control plantation than in either test plantation. Also, a significant year-by-site interaction for air temperature has been shown to be related to differences in red pine seedling growth at the study sites. A relatively weak, though significant, correlation has been calculated between air temperature (2 m, annual plot or site averages, 1985-1989) and longitudinal and magnetic EW leg antenna operation 76 hz field strengths. It appears that this relationship may also be related to seedling growth, because neither hardwood stand air temperature (30 cm) nor soil

temperature (5 cm) are similarly correlated with 76 hz field strengths. The ELF-independence of rhizosphere pH and "delay" remain to be evaluated.

Levels of Mycorrhizoplane Streptomycetes

The mean levels of mycorrhizoplane streptomycetes, with their associated CV values, are presented in Tables 2.3-2.5, for each sampling date, at the three study plantations (ground, antenna, and control sites, respectively). The relatively large CV values (and missing data) for 1989 and 1990 are associated with insufficient or inadequate samples (less than six samples provided per site or insufficient sample mass provided) and/or with bacterial or fungal contamination of several of the samples.

The three-way ANOVA model for comparisons of streptomycete levels among years, sampling dates and plantations detected significant differences among years, months, and plantations. The year-by-site interaction was also significant. Streptomycete levels for 1985, 1986, 1989, and 1990 were not significantly different from each other, but were significantly lower than the 1987 and 1988 levels, which also were similar. Levels at the control plantation were slightly lower than those at the antenna and ground plantations. Significantly lower levels were documented in October.

Detection limits for streptomycete levels are presented in Table 2.6. Detection limits were estimated for each year and plantation included in the final ANACOV model (Table 2.7). Calculation of detection limits was based on back-transformation of confidence intervals derived from the least squares means provided by the Least Squares Means option of PROC GLM, SAS. Shifts in streptomycete levels of 19 percent among years, or of 12 percent among plantations, should be reasonably detectable.

The differences among years and plantations, as well as the

Table 2.3. Summary of measured variables, Element 2. Levels of mycorrhizoplane streptomycetes (x 10^5), with corresponding percent CV[a], isolated from type 3 red pine mycorrhizae at the Ground Plantation.

Year		Month					
		May	Jun	Jul	Aug	Sep	Oct
1985	Mean	9.04	3.91	4.14	4.59	3.56	9.25
	CV	77.0	89.9	71.2	37.3	93.1	13.7
1986	Mean	3.84	4.56	2.18	2.86	2.87	1.19
	CV	27.2	35.1	24.6	37.5	45.0	26.0
1987	Mean	3.81	3.57	5.15	4.24	5.99	1.52
	CV	38.4	54.6	28.8	28.4	31.9	28.4
1988	Mean	3.17	4.49	5.01	4.74	6.00	2.15
	CV	28.1	13.7	12.5	21.0	9.0	33.5
1989	Mean	2.29	3.42	3.96	2.24	2.53	1.67
	CV	-	25.3	14.6	45.8	39.9	35.1
1990	Mean	2.88	-	3.98	4.33	3.60	-
	CV	56.6	-	-	32.9	29.5	-

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 2.4. Summary of measured variables, Element 2. Levels of mycorrhizoplane streptomycetes (x 10^5), with corresponding percent CV[a], isolated from type 3 red pine mycorrhizae at the Antenna Plantation.

Year		Month					
		May	Jun	Jul	Aug	Sep	Oct
1985	Mean	4.50	5.14	4.54	2.73	4.53	1.47
	CV	34.9	54.6	7.3	42.4	51.9	49.1
1986	Mean	4.73	3.91	3.35	2.79	2.60	1.14
	CV	44.5	32.8	40.9	36.8	33.4	18.9
1987	Mean	3.58	5.06	4.60	4.55	6.75	1.78
	CV	42.9	27.6	44.8	45.0	24.4	15.8
1988	Mean	3.62	3.35	4.07	4.76	5.97	1.83
	CV	27.2	29.0	13.2	14.8	12.1	51.3
1989	Mean	2.69	2.19	1.61	2.10	2.78	1.91
	CV	26.9	21.3	8.1	66.8	34.6	43.5
1990	Mean	2.84	2.16	4.54	3.77	3.64	-
	CV	61.3	46.2	58.0	24.7	35.2	-

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 2.5. Summary of measured variables, Element 2. Levels of streptomycetes (x 10^5), with corresponding percent CV[a], isolated from type 3 red pine mycorrhizae at the Control Plantation.

Year		Month					
		May	Jun	Jul	Aug	Sep	Oct
1985	Mean	4.54	9.09	1.65	-	1.34	1.04
	CV	62.1	23.7	52.0	-	52.2	44.5
1986	Mean	4.20	4.14	3.49	2.18	2.22	1.09
	CV	42.0	56.2	52.5	25.5	60.1	23.5
1987	Mean	3.97	5.66	4.14	6.27	6.53	1.56
	CV	35.0	32.6	39.7	24.9	21.5	60.1
1988	Mean	3.35	3.81	4.81	5.31	6.03	1.74
	CV	32.5	33.0	19.3	15.8	19.3	42.3
1989	Mean	3.07	2.62	3.13	2.13	3.19	1.39
	CV	30.2	56.2	33.6	34.0	35.1	22.0
1990	Mean	3.96	3.57	2.75	3.95	3.85	-
	CV	44.5	32.8	16.6	11.3	51.3	-

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 2.6. Summary of measured variables, Element 2.

Variable	Treatment	Detection Limit (%)[a]	Pre-operational Years[b]	Post-operational Years[b]
Levels of Mycorrhizoplane Streptomycetes (x 10^5)				
	Year		1986-1989	1990-1991
	1986	13.13		
	1987	18.61		
	1988	13.13		
	1989	12.67		
	1990	17.69		
	1991	NYA[c]		
	Site			
	Ground	10.85		
	Antenna	8.13		
	Control	11.31		
Numbers of Streptomycete Morphotypes				
	Year		1987-1989	1990-1991
	1987	15.10		
	1988	15.50		
	1989	13.59		
	1990	18.16		
	1991	NYA		
	Site			
	Ground	10.52		
	Antenna	8.42		
	Control	8.06		

a/ Percentage change in the variable for which there is a 50 percent chance of detection at $p = 0.05$.
b/ Pre-operational years are defined as years prior to full power (150 amp) antenna operation in 1990; post-operational years are 1990 and 1991.
c/ Data are not yet available.

Table 2.7. Summary of statistical analyses and results for measured variable, Element 2.

Variable	Test Procedure[a]	Covariates[b] (If Appropriate)	Treatments	Findings Through 1990[c]
Levels of Mycorrhizoplane Streptomycetes (x 10^5)				
	ANACOV	pH ATDDRT PRWRT PR.10RT	Year, Site	No Detectable Effect
Numbers of Streptomycete Morphotypes				
	ANACOV	DELAY ST5DDRT PR.10RT	Year, Site	No Detectable Effect

a/ ANACOV = Analysis of Covariance (PROC GLM, SAS)

b/ pH = pH of rhizosphere soil associated with sampled seedlings; ATDDRT = air temperature degree days running total (April - Sample Date); ST5DDRT = soil temperature (5 cm depth) degree days running total (April - Sample Date); PRWRT = precipitation amount running total (April - Sample Date); PR.10RT = number of precipitation events delivering at least 0.1 inches running total (April - Sample Date); DELAY = number of days between seedling excavation and delivery of samples for streptomycete analysis.

c/ All statistical tests are at $\alpha = 0.05$.

year-by-site interaction, detected by ANOVA were all explained by the ANACOV model with four covariates: 1) mycorrhizoplane soil pH, and seasonal running totals of 2) air temperature degree days, 3) total precipitation, and 4) numbers of precipitation events delivering at least 0.1 inches. However, October levels remained lower than those of any other month.

Numbers of Mycorrhizoplane Streptomycete Types

The mean numbers of mycorrhizoplane streptomycete morphotypes recovered, with their associated CV values, are presented in Tables 2.8-2.10, for each sampling date, at the three study plantations (ground, antenna, and control sites, respectively). Again, the relatively large CV values and missing data for 1989 and 1990 are associated with insufficient or inadequate samples, and/or with bacterial or fungal contamination of several of the samples.

The three-way ANOVA model for comparisons of streptomycete morphotype numbers among years, sampling dates and plantations detected significant differences among years and months, but not among the three plantations. The year-by-site interaction was not significant. The numbers of observed morphotypes declined from 1985 to 1986 and from 1986 to 1987. No further decline, from 1987-1989, is apparent. However, morphotype numbers in 1990 were lower than those for 1987. This initial decline and then stabilization may reflect the establishment and persistence of those streptomycete types most capable of growth and survival with the red pine mycorrhizae at these sites. Morphotype numbers in October were significantly lower than those found from May to September, and May numbers were significantly higher than those found from July to October.

Detection limits for morphotype numbers are presented in Table 2.11, for each year and plantation included in the final ANACOV model (Table 2.7). Shifts in morphotype numbers of 19 percent

Table 2.8. Summary of measured variables, Element 2. Numbers of streptomycete morphotypes, with corresponding percent CV[a], isolated from type 3 red pine mycorrhizae at the Ground Plantation.

Year		Month					
		May	Jun	Jul	Aug	Sep	Oct
1985	Mean	7	6	5	5	6	4
	CV	13.7	0.0	20.4	10.9	18.7	43.5
1986	Mean	7	6	4	4	4	3
	CV	30.5	21.9	12.3	22.0	22.0	22.4
1987	Mean	4	3	3	3	3	3
	CV	22.3	14.9	23.5	23.5	14.9	30.6
1988	Mean	4	4	3	3	4	3
	CV	29.9	22.0	41.4	41.0	18.1	30.6
1989	Mean	3	3	3	3	2	2
	CV	-	25.3	0.0	33.2	23.3	71.1
1990	Mean	3	-	3	3	3	2
	CV	45.7	-	-	25.9	25.9	0.0

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 2.9. Summary of measured variables, Element 2. Numbers of streptomycete morphotypes, with corresponding percent CV[a], isolated from type 3 red pine mycorrhizae at the Antenna Plantation.

Year		Month					
		May	Jun	Jul	Aug	Sep	Oct
1985	Mean	6	6	5	6	5	4
	CV	32.9	33.1	10.9	9.5	45.2	35.4
1986	Mean	7	6	5	4	3	3
	CV	13.3	24.7	15.9	15.0	36.9	26.5
1987	Mean	3	5	3	4	4	3
	CV	30.9	11.4	14.9	29.9	29.9	29.6
1988	Mean	3	3	3	3	5	3
	CV	24.3	34.6	45.4	41.4	14.8	19.8
1989	Mean	5	4	4	3	3	3
	CV	31.0	39.6	33.5	16.6	30.0	82.5
1990	Mean	4	3	2	4	4	3
	CV	37.2	22.1	25.3	34.2	30.6	23.6

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

Table 2.10. Summary of measured variables, Element 2. Numbers of streptomycete morphotypes, with corresponding percent CV[a], isolated from type 3 red pine mycorrhizae at the Control Plantation.

Year		Month					
		May	Jun	Jul	Aug	Sep	Oct
1985	Mean	7	5	4	-	5	4
	CV	9.0	22.1	13.8	-	22.1	24.9
1986	Mean	7	5	4	3	4	3
	CV	29.0	19.9	18.1	14.9	27.9	26.5
1987	Mean	4	4	3	3	3	3
	CV	22.0	22.3	23.7	23.7	30.6	22.4
1988	Mean	3	2	3	3	4	3
	CV	19.8	22.6	41.4	30.9	37.4	19.8
1989	Mean	4	3	4	4	4	3
	CV	30.6	16.6	23.7	30.6	27.3	46.0
1990	Mean	3	2	2	4	4	2
	CV	25.9	0.0	23.3	19.9	35.1	33.4

a/ Coefficient of Variation, calculated as (standard deviation/mean)*100.

among years, or of 11 percent among plantations, should be reasonably detectable. Considering the small numbers of morphotypes characteristically recovered from any given sample (see Tables 2.8-2.10), a reduction in this variable of 1.0 morphotype per sample might well be detected. Nevertheless, because most morphotypes are not routinely recovered from every sample, it might be necessary for several of the less abundant morphotypes to decline in abundance in order to effect a reduction of 1.0 in morphotype numbers recovered.

All differences among years and sampling dates detected by three-way ANOVA were explained by the ANACOV model with three covariates: 1) processing delay (beyond our control), and running totals of 2) soil temperature degree days (5 cm) and 3) numbers of precipitation events delivering at least 0.1 inches.

Morphotype Distribution and Characterization

In general, the same morphotypes and same incidence patterns have been found from 1986 through 1990. Morphotype B has been detected at each plantation on each sampling date; it was usually found in multiple samples/plantation per date, often as the predominate type. Morphotypes D, J, S, T, and U were commonly detected in 1987 through 1990. Morphotype F levels were similar in 1989 and 1990, i.e., much less frequent than in previous years. Levels of morphotypes A, K, and W increased in 1990, following a drop in 1989. Frequencies of isolation of morphotypes E, N and R were lower in 1990 than in 1989; however, these levels were again more similar to those found prior to 1989. Detection of morphotypes was made more difficult in 1990, due to the increased overgrowth of media plates with saprotrophic fungi and non-streptomycete bacteria. This was particularly the case with the ground plantation samples, which have had an elevated level of "contamination" in past years as well.

Other similarities were present in common morphotype incidence

among those plantation site samples consisting only of mycorrhizal type 3 fine roots, i.e., 1986 - 1990. For the control plantation, the incidence pattern found in 1990 was very similar to that found in 1989, except that types A and W were more commonly found and type F less commonly found than in 1989. The incidences of types B, D, J, and S were about the same for all five years. Morphotypes B, D, and K were commonly found with the antenna plantation samples from 1986-90. In general, the overall 1990 morphotype incidence patterns were more like those found in 1987 and 1988 than in 1986 or 1989. Morphotype H, which previously has been detected commonly only in the 1989 antenna plantation samples, was again found mainly with the antenna samples. There were again relatively few ground plantation sample morphotype data for the 1990 season, primarily due to contamination problems (as noted above). Morphotype B was therefore the only commonly detected type. The incidences of morphotypes A, N, and S appeared to be similar to earlier sampling seasons, while incidences of types D, J, and R were lower than those found in earlier years.

Summary of Results

ANACOV has been successfully used to explain all differences detected by three-way ANOVA, in either streptomycete levels or morphotype numbers, among years and study plantations. No significant year-by-site interaction was found for morphotype numbers, and that found for streptomycete levels was explained by the preferred ANACOV. No potential effect of ELF field exposure has been identified through the 1990 field season. Data for the 1991 field season will be incorporated into the analysis as soon as they become available.

Detection limits calculated for both streptomycete levels and morphotype numbers indicate that we have a little better than a 50 percent chance ($\alpha = 0.05$) of detecting shifts in either of these variables of 20 percent among years, and 12 percent among

plantations. Shifts of this magnitude would likely require declines in abundance (or outright loss) of several of the approximately 20 streptomycete morphotypes observed over the past six years.

Proposed Work

Analyses in 1991 continued to deal with determination of streptomycete levels and morphotype numbers associated with washed red pine type 3 mycorrhizal fine roots. Though mycorrhizae studies are proposed to continue in the field in 1992, we do not anticipate further streptomycete data collection. The resulting data will be available for analysis, final report preparation, and publication, during 1992.

Element 2. Armillaria Root Disease Epidemiology

Introduction

The ongoing Armillaria root disease epidemics in the three red pine study plantations have been thoroughly documented since their onset in 1986. Armillaria root disease is of interest to the Ecological Monitoring Program because 1) it is the only lethal contagious disease of red pine occurring in the study plantations, 2) it is often stress-induced, and 3) it is the only plant disease which has received attention in the Ecological Monitoring Program. Armillaria species are white rot fungi which colonize and decay woody debris, stumps, and moribund root systems. These foodbases are colonized by means of airborne spores and/or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize the next. Red pines may become infected by rhizomorphs or by root growth into contact with decaying foodbases.

The Armillaria root disease study element involves evaluation of potentially subtle ELF EM field effects on the activities of communities of microorganisms. Armillaria species are represented by potentially very large and long-lived individuals, which have remarkable potential for vegetative growth and spread (Smith et al. 1990, 1992). While we do not have the means to test for an effect of ELF EM fields on initial clone establishment, we can test for an effect of ELF EM fields on the rates of disease progress of existing clones. Field work must continue during full antenna operation to provide sufficient data for evaluation of possible ELF EM field effects on this important factor affecting forest health.

The decision to continue data collection for the Armillaria root disease work element is based on somewhat different criteria from those applied to the litter decomposition study element. It is important to realize that funding was not originally proposed for

study of potential ELF EM field effects on Armillaria root disease epidemiology, because the disease could not be shown to be present at the outset of the Ecological Monitoring Program studies. Indeed, the host populations (the red pine plantations) were created after the studies were established! The Armillaria root disease work element has been adopted by the Litter Decomposition and Microflora project as of FY92 (from the Upland Flora project), as we propose to discontinue the mycorrhizoplane streptomycete work element and begin to scale back the litter decomposition work element. Resources in past years have permitted documentation of the epidemics and gradual preparation of the database needed for statistically sound investigation of the epidemic in each study plantation. Sufficient resources have not been available to both prepare the database and analyze it simultaneously. The decision to continue data collection and to complete the statistical analysis for the Armillaria root disease work element has been made based on the following criteria:

1. Armillaria root disease, the only lethal disease of red pine present in the study plantations, is the only plant disease under study in the Ecological Monitoring Program. This disease has killed between 1 and 33 percent of the host population, depending on location.

2. There is good reason to expect that additional mortality due to this disease will continue to occur, because: a) adequate woody foodbases occur on the sites, b) clones of the highly pathogenic A. ostoyae have been identified, c) documented epidemics in the Lake States have peaked after 10 years of activity, and d) the rates of mortality in the 3 ELF study plantations have shown no sign of abatement.

3. There is a strong association between Armillaria root disease severity and host (i.e., red pine) health. In other words, various stresses (possibly including ELF EM fields) predispose host plants to successful infection by Armillaria ostoyae.

4. Because Armillaria root disease is readily diagnosed, it is possible to accurately map and statistically model disease progress.

5. Mapping data for 1) the red pine host populations, 2) the historical spatial distribution of Armillaria individuals in these red pine plantations, and 3) ELF EM field strengths all have become available for analysis only within the past year.

Methods

It is clear, from the uneven spatial distributions of host seedlings in the three study plantations, that comparison of mortality counts among plantations (or quarterplots) is a totally inappropriate test of ELF EM field effects on Armillaria root disease progress. The appropriate measure of disease progress is the decimal proportion (Y_i) of the initial host seedling population which has been killed by Armillaria root disease at any specified point in time. The initial host seedling population is defined as the number of living seedlings at the beginning of the 1986 field season. This starting point was selected because 1) the first Armillaria root disease mortality in the study plantations occurred in 1986, and 2) at two years of age in 1986, the plantations were beyond the point of experiencing mortality due to planting stress. Analyses of Armillaria root disease progress are simplified by the absence of other lethal infectious diseases in the study plantations. The analysis reported here is based on disease progress in each of the 12 quarterplots comprising each plantation. Y_i is calculated as the cumulative mortality count divided by the initial host seedling count reduced by the number of healthy seedlings removed for experimental purposes.

The pathogen is isolated into pure culture from each seedling killed by Armillaria root disease. Isolates are also obtained

each autumn from Armillaria mushrooms collected in the plantations. Isolates are grown in confrontation with each other in Petri dish culture for identification of vegetatively compatible groups of isolates. Vegetatively compatible isolates have been shown to belong to the same vegetative individual or clone (Smith et al. 1990, 1992). Each clone is then identified to species. So far, all identified clones responsible for red pine mortality in the study plantations belong to a single species, A. ostoyae (Romagnesi) Herink. Clones of A. gallica Marxmuller & Romagnesi are also widespread in the plantations, but are not pathogenic on red pine.

Construction of historical (1986 to present) maps of the spatial distribution of clones of each species is nearly up-to-date. Once we are able to estimate the spatial boundaries of each clone, we will be able to determine the "initial" host population counts for the area occupied by each clone. This will permit statistical analysis of the rate of disease progress on an individual clone basis, as well as on a quarterplot basis (see below). Analyses based on the areas occupied by individual clones are attractive, because they restrict calculations of disease progress to the portion of the host population accessible by individual pathogen genotypes (clones).

The distributions of available target host plants vary greatly within and among plantations, largely due to initial planting failure. It is therefore essential (for calculation of Y_i) to document these spatial distributions, in order to establish initial host populations within quarterplot or clone boundaries. During the winter of 1990/1991, the entire live seedling populations in the study plantations were mapped and tagged. Prior to this mapping effort, only seedlings killed by root disease, seedlings removed for experimental purposes, and hardwood stumps had been mapped. Beginning in 1991, as seedlings are killed by root disease, their change of status from living to mortality is noted in a historical data set, along with the date

of diagnosis. This data set is complete, from 1986 to present. Unlike other studies at these sites, the Armillaria root disease studies are based on 100 percent surveys of each plantation. As a result, the adequacy of root disease documentation for the three epidemics is not an issue.

A variety of mathematical models have been used to describe and compare disease progress among plant disease epidemics (Campbell and Madden 1990, Madden and Campbell 1990). Our preliminary analysis of the epidemics in the three study plantations has considered the monomolecular, Gompertz, logistic, and Richards models. The integrated forms of these models are:

monomolecular: $y = K(1-Be^{-rt})$

Gompertz: $y = Kexp(-Be^{-rt})$

logistic: $y = K/(1+exp(-(B+rt)))$

Richards: $y = K(1-Be^{-rt})^{1/(1-m)}$, when m<1, and
$K(1+Be^{-rt})^{1/(1-m)}$, when m>1.

The linearized forms of these models are:

monomolecular: $\ln(K/(K-y)) = -\ln(B)+rt$

Gompertz: $-\ln(-\ln(y/K) = -\ln(B)+rt$

logistic: $\ln(y/(K-y)) = \ln(y_0/(K-y_0))+rt$

Richards: $\ln(1/(1-(y/K)^{(1-m)})) = -\ln(B)+rt$, when m<1, and
$\ln(1/((y/K)^{(1-m)}-1)) = -\ln(B)+rt$, when m>1.

In the above equations, y is the level of disease at time t, K is the maximum level of disease attainable (y_{max}, presently presumed K=1.00), B is a constant of integration, y_0 is the initial level of disease (y_0 = 0.00), e is the base of natural logarithms, r is a rate parameter with units of time^{-1}, exp represents e raised to some specified power, and m is a shape parameter with values ranging from 0 to infinity.

Rate constants for disease progress were estimated for each of the 12 quarterplots comprising each plantation, using each of the models listed above. For each model, the appropriately transformed y_i was regressed versus air temperature degree days accumulated since plantation establishment in the spring of 1984

(CUATDD). CUATDD was selected as a surrogate for elapsed time, because of the temperature dependency of biological activity and the long winters in the study area. The most appropriate disease progress model for each quarterplot was identified by comparing the values of R^2, the mean square error, and the standard error of the rate estimate, and by comparing the plots of the standardized residuals versus predicted values (Campbell and Madden 1990). The rate parameters derived for each plantation were then compared using ANOVA (Madden 1986). However, because the data from 29 of the 36 quarterplots were best fit by the monomolecular model, while data from the remaining 7 quarterplots were best fit by the Gompertz model, rate parameter estimates could not be compared directly. Therefore, ANOVA was performed on the "weighted mean absolute rate of increase", $r' = rK/(2m+2)$, where $m = 0$ corresponds to the monomolecular model and $m = 1$ corresponds to the Gompertz model (Madden and Campbell 1990).

In addition to comparing the three plantations using rate constants based on all years, we would like to compare rate constants derived from pre- and post-operational years' data for each of the three plantations. However, this analysis will require field data for 1992 and 1993, in order to have four years of post-operational data (1990-1993) to compare with our four years of pre-operational data (1986-1989).

All regressions and ANOVAs have been conducted on the mainframe computer, using PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985). In all statistical analyses, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$, regardless of the statistical test employed. Significant differences detected by ANOVA have been identified by the Least Square Means pairwise comparison option, within PROC GLM.

We expect ANACOV to play an important role in explaining the differences detected by ANOVA among plantations. Covariates to be considered may include precipitation-related variables, mean

seedling height, and/or characteristics of the hardwood stump foodbase populations in each plantation. These populations have been mapped, and stump size and species recorded. Also, in 1987 and 1991, the condition of each stump was documented as either living or dead, and the number of sprouts and maximum sprout height were recorded for each living stump.

Description of Progress

Our maps of Armillaria clones (Figures 3.1 - 3.3) suggest that clones of the same Armillaria species overlap little, whereas clones of different Armillaria species overlap freely. It should therefore be possible to analyze rates of disease progress within the boundaries of individual clones of A. ostoyae. This would address concern over the variation among quarterplots in proportion of area occupied by A. ostoyae.

Rate parameter values for disease increase in each of the 36 quarterplots are presented in Table 3.1. The underlying disease progress model is identified, and the weighted mean absolute rate of disease increase (r′) is also provided for each quarterplot. Mean r′ values for each plantation, along with their associated standard errors and CV values, are presented in Table 3.2. Quarterplots with less than half of their area apparently occupied by A. ostoyae were not included in the analysis presented here. This reduced the number of quarterplots included in the analysis to 6 for the ground plantation, and 9 for the antenna plantation. Nevertheless, the relatively large CV values may still be largely due to variation among quarterplots in the proportion of their area occupied by A. ostoyae.

The results of preliminary ANOVA for detection of differences in r′ among the three plantations, based on the quarterplots represented in Table 3.2, are presented in Tables 3.3 and 3.4. Significant differences among plantations were detected by ANOVA ($p = 0.0034$), and the least squares means pairwise comparison

Figure 3.1. Preliminary historical map of the Armillaria root disease epidemic in the ground site plantation. *Armillaria* clones are outlined; the red clone at top center is *A. gallica*, the rest are *A. ostoyae*. Legend: L = live seedling; R# = seedling removed for experimental purposes (# = last digit of year removed); M# = seedling killed by Armillaria root disease.

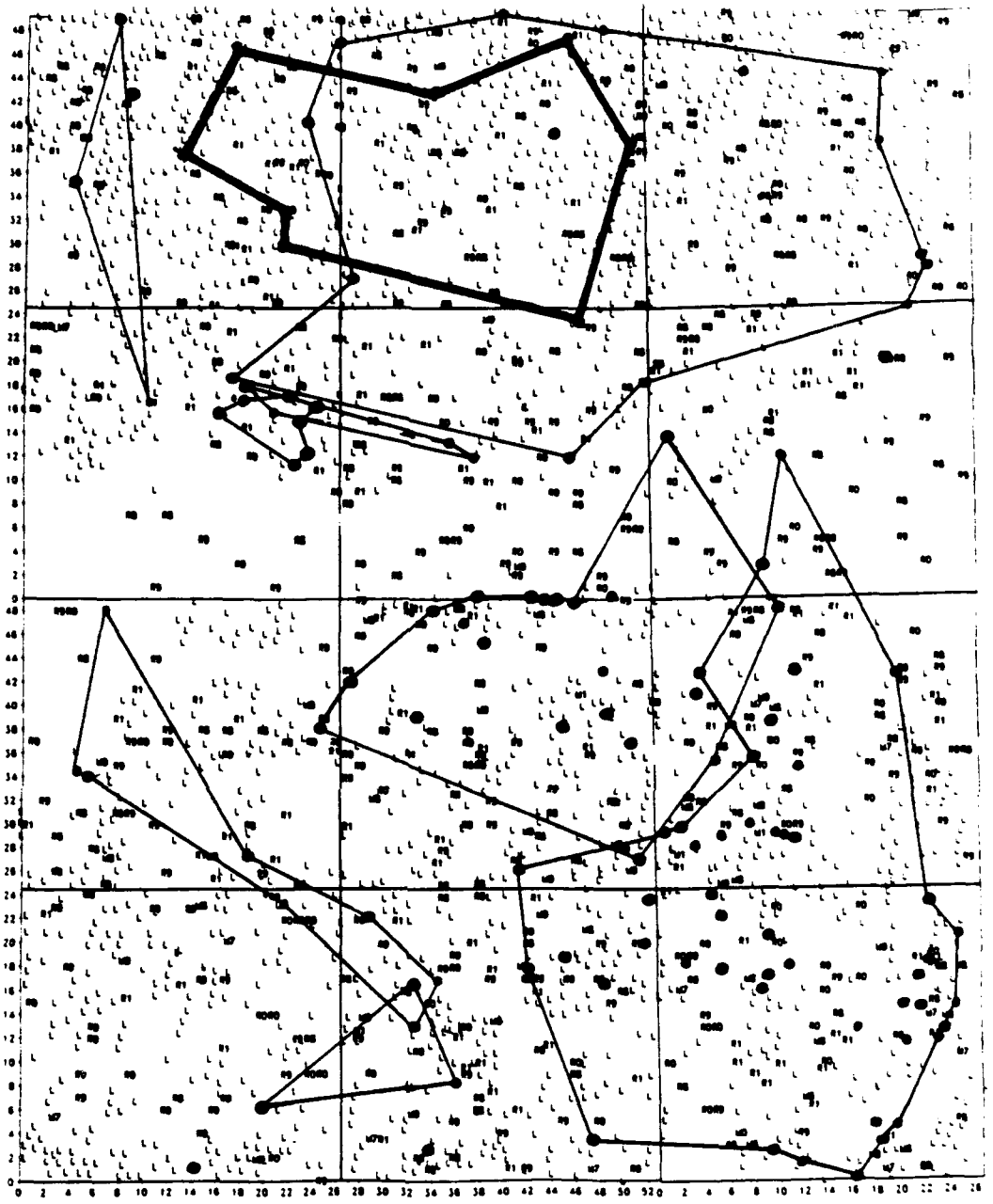

Figure 3.2. Preliminary historical map of the Armillaria root disease epidemic in the antenna site plantation. Armillaria clones are outlined; the red clone covering most of the plantation is A. gallica, the rest are A. ostoyae. Legend: L = live seedling; R# = seedling removed for experimental purposes (# = last digit of year removed); M# = seedling killed by Armillaria root disease.

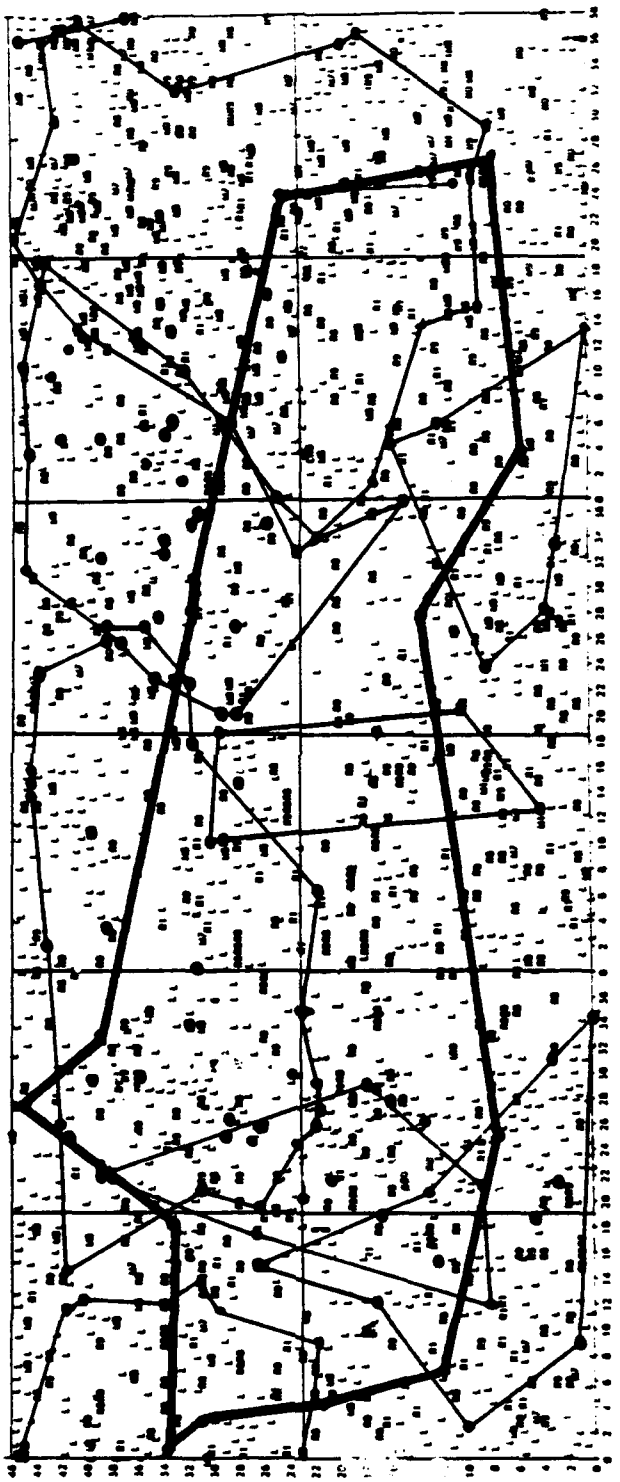

Figure 3.3. Preliminary historical map of the Armillaria root disease epidemic in the control site plantation. Armillaria clones are outlined; the red clone at the left edge of the plantation is A. gallica (the rest of the plantation is covered by a second undepicted A. gallica clone), the rest are A. ostoyae. Legend: L = live seedling; R# = seedling removed for experimental purposes (# = last digit of year removed); M# = seedling killed by Armillaria root disease.

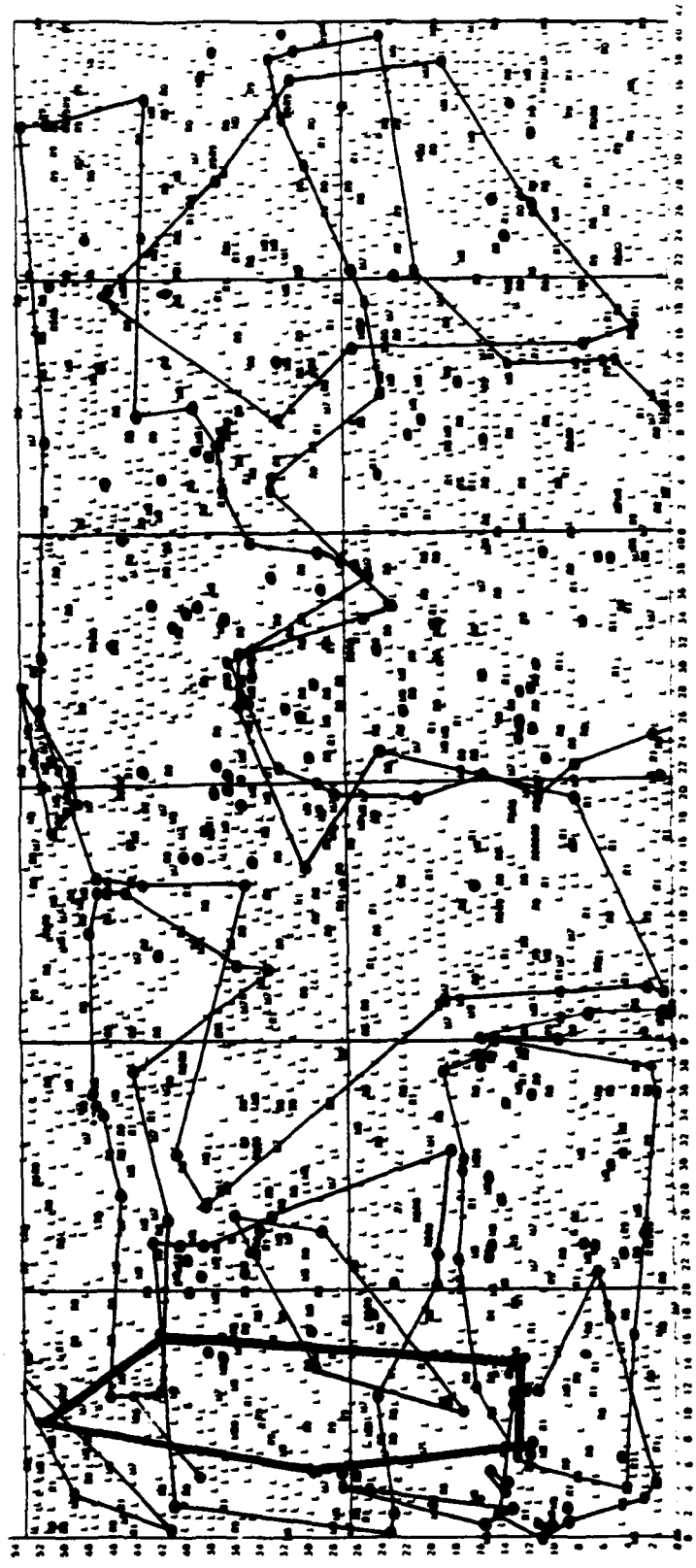

Table 3.1. Rates of disease increase[1] from disease progress curves for mortality caused by Armillaria root disease on each of the plantation study quarter-replicates.

Site	Block	QtrRep	r*	Model[2]	r'
1	1	1	0.0011267	Monomolecular	0.00056337
1	1	2	0.0001798	Monomolecular	0.00008990
1	1	3	0.0008418	Monomolecular	0.00042098
1	1	4	0.0127083	Gompertz	0.00317706
1	2	5	0.0003968	Monomolecular	0.00019838
1	2	6	0.0007782	Monomolecular	0.00038911
1	2	7	0.0077810	Gompertz	0.00194524
1	2	8	0.0120321	Gompertz	0.00300803
1	3	9	0.0025895	Monomolecular	0.00129474
1	3	10	0.0020511	Monomolecular	0.00102557
1	3	11	0.0100082	Gompertz	0.00277706
1	3	12	0.0093887	Gompertz	0.00234718
2	1	13	0.0012240	Monomolecular	0.00061200
2	1	14	0.0015423	Monomolecular	0.00077114
2	1	15	0.0006677	Monomolecular	0.00033386
2	1	16	0.0012434	Monomolecular	0.00062170
2	2	17	0.0146005	Gompertz	0.00365013
2	2	18	0.0016756	Monomolecular	0.00083779
2	2	19	0.0018017	Monomolecular	0.00090083
2	2	20	0.0145104	Gompertz	0.00362761
2	3	21	0.0023813	Monomolecular	0.00119063
2	3	22	0.0050386	Monomolecular	0.00251932
2	3	23	0.0031585	Monomolecular	0.00157926
2	3	24	0.0039001	Monomolecular	0.00195004
3	1	25	0.0027634	Monomolecular	0.00138172
3	1	26	0.0016584	Monomolecular	0.00082918
3	1	27	0.0022071	Monomolecular	0.00110355
3	1	28	0.0019832	Monomolecular	0.00099158
3	2	29	0.0013719	Monomolecular	0.00068597
3	2	30	0.0016676	Monomolecular	0.00083381
3	2	31	0.0018320	Monomolecular	0.00091599
3	2	32	0.0016441	Monomolecular	0.00082203
3	3	33	0.0015539	Monomolecular	0.00077693
3	3	34	0.0012369	Monomolecular	0.00061843
3	3	35	0.0008143	Monomolecular	0.00040713
3	3	36	0.0009610	Monomolecular	0.00048052

[1] r* is the rate coefficient for the model which best fits the disease progress data (either monomolecular or Gompertz); r' is the weighted mean absolute rate of disease increase, $r'=rK/(2m+2)$, where r is r*, K is the maximum disease level (presently presumed to be 1.0), and m is a shape parameter for which m=0 corresponds to the monomolecular model and m=1 corresponds to the Gompertz model (Madden and Campbell 1990).

[2] The two models tested in this initial analysis have the following linearized forms:
1) monomolecular model, $\ln[K/(K-y)] = -\ln(B)+rt$;
2) Gompertz model, $-\ln[-\ln(y/K)] = -\ln(B)+rt$;
where y is the amount of disease present, y_0 is the initial amount of disease (0.0, in our case), r is the rate of disease increase corresponding to r*, and t is a function of elapsed time (degree days in our case).

Table 3.2. Weighted mean absolute rates (r′) of disease increase[1] for each study plantation, from the disease progress curves for mortality caused by Armillaria root disease on each of the study plantations quarterplots (excluding those quarterplots[2] with less than half of their area apparently occupied by A. ostoyae).

Site	N	Mean	S.E.	C.V.
Antenna Ground	6	0.00213297	0.00035898	41.225
Antenna Overhead	9	0.00152328	0.00034147	67.249
Control	12	0.00082057	0.00007692	32.473

1 r′=rK/(2m+2), where r is the rate constant for either the monomolecular or Gompertz model of disease progress, K is the maximum disease level (presently presumed to be 1.0), and m is a shape parameter for which m=0 corresponds to the monomolecular model and m=1 corresponds to the Gompertz model (Madden and Campbell 1990, Campbell and Madden 1990).

2 Quarter-replicates 1, 2, 3, 5, 6, and 11, from the ground antenna site, and quarter-replicates 15, 17, and 19, from the overhead antenna site, were not included in this analysis.

Table 3.3. ANOVA table for detection of differences in weighted mean absolute rate (r′) of disease increase, from the Armillaria root disease mortality progress models for each of the plantation quarter-replicates with at least half of their area occupied by Armillaria.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2	CV
Model	8	0.0000137		4.61	0.0034	0.67	45
Site	2	0.0000073	0.0000092				
Block (Site)	6	0.0000064	0.0000064				
Error	18	0.0000067					
Corrected Total	26	0.0000204					

Table 3.4. Adjusted means, standard errors, detection limits, and significantly different pairs of means, based on the model analyzed in Table 3.3.

Source of Variation	Adjusted Mean[a]	Standard Error	Detection Limit[b]	Significant Differences[c]		
Site				1	2	3
1	0.00240318	0.00027488	22.41	1		
2	0.00157027	0.00021130	26.38	2	*	
3	0.00082057	0.00017581	41.99	3	*	*

[a] mean of r′ values
[b] percentage change in the variable for which there is a 50 percent chance of detection at p = 0.05.

procedure ranked disease progress rates as ground > antenna > control, in order of descending magnitude. Detection limits for each plantation are also presented in Table 3.4. Their relatively large size may simplify the matter of explaining the differences detected by ANOVA. On the other hand, clone-based analysis may provide lower CV values and detection limits than have the quarterplot-based analysis reported here.

Summary of Results

Maps of the spatial distribution of Armillaria clones for all three plantations indicate that individual clones of A. ostoyae overlap very little. As a result, it will be possible to compare disease progress rates based on the land area occupied by individual genotypes (clones). Analysis on an individual clone basis, rather than on a quarterplot basis, should reduce CV values and detection limits, by including only that portion of each plantation which is colonized by clones of the pathogen.

Preliminary ANOVA study of the weighted mean absolute rates of disease increase (r'), for all quarterplots with at least half of their land area occupied by an A. ostoyae clone, found that r' was greatest in the ground plantation and lowest in the control plantation.

Data have been collected for a substantial ANACOV effort. Potential covariates include precipitation-related variables, mean seedling height, and variables which characterize the hardwood stump population.

Proposed Work

We propose to continue documenting the seedling mortality caused by individual clones of A. ostoyae during 1992 and 1993. This will give us four years of study with the fully-operational ELF system. We propose to use the resulting data to analyze disease

progress rates on both an individual clone basis and on a quarterplot basis. In addition to comparing the three plantations using rate constants based on all years, we propose to compare rate constants derived from pre- and post-operational years' data for each of the three plantations. We propose to use ANACOV to explain differences among plantations in disease progress rates (r') detected by ANOVA.

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GLOSSARY

Actinomycete	A large group of true bacteria, characterized by a mycelial vegetative structure.
AET	Actual evapotranspiration: a measure of the cumulative and concurrent availability of energy and moisture.
Basal Area	The area of the cross section of a tree at DBH.
Biomass	The amount of living matter in a unit area.
DBH	Diameter at breast height. Average stem diameter, outside bark, measured 4.5 feet above the ground.
Ectomycorrhizae	The type of mycorrhizae in which the fungus component grows only intercellularly within its host root, and produces an external mantle.
Foodbase	Any piece of woody debris suitable for colonization by Armillaria species.
Habitat Type	Land areas potentially capable of producing similar plant communities at maturity.
Litter	Dead, largely unincorporated leaves and other plant parts on the forest floor.
Mycorrhizae	A mutually beneficial association between plant roots and certain highly specialized parasitic fungi.
Mycorrhizoplane	The rhizoplane of mycorrhizae.
Mycorrhizosphere	The rhizosphere of mycorrhizae.
NESS	National Earth Satellite Service.
NOAA	National Oceanographic and Atmospheric Administration.
Nutrient Flux	In litter decomposition, the balance between the rates of nutrient movement into and out of decomposing litter.
Rhizomorph	The infective cord-like organs, produced by Armillaria species, composed of differentiated hyphal aggregates, for growth through the soil and colonization of new foodbases.
Rhizoplane	The actual surface of plant roots, together with any closely adhering particles of soil or debris.
Rhizosphere	The narrow zone of soil subject to the influence of living roots.
Streptomycete	Members of the genus Streptomyces, a group of actinomycetes which reproduce by forming spores.